ORIGIN STORY: DEEPTIME PLATYPUSES AND AUSTRALIA'S MONOTREME MYSTERY

COSMOS

THE SCIENCE OF EVERYTHING

Issue 95

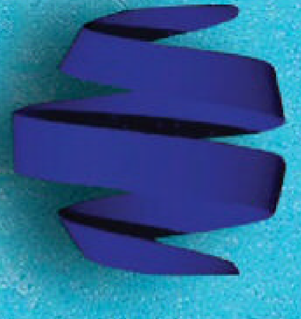
Would you alter an animal's DNA to save it from extinction?

APP GAP
Cracking software's shell

DRIVE MY CAR?
The case for and against UAVs

Does loneliness affect our cells and genes?

GAME CHANGERS



Is the W boson about to tranform everything we think we know?

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SCIENCE OF SUCCESS • SAUSAGES UNZIPPED • QUANTUM ENGINEERING

Home sweet sphagnum

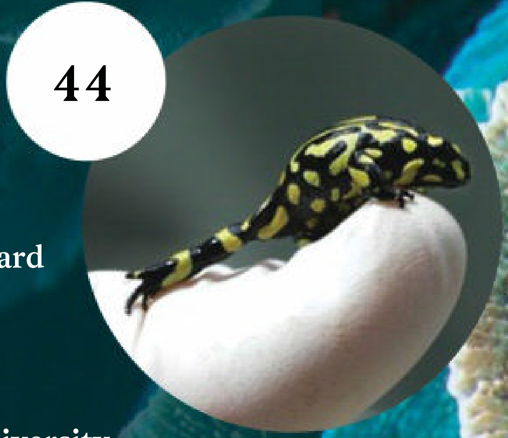
Perched on a scientist's gloved hand, four of the 100 southern corroboree frogs (*Pseudophryne corroboree*) released in Kosciuszko National Park, NSW, in March prepare to go wild. Captive bred, the frogs were returned to the Snowy Mountains habitat they favour – including sphagnum bogs and wet tussock grassland and heath – in time to acclimatise before winter snows arrived. To learn more about the remarkable, and controversial, effort to save this beautiful and critically endangered amphibian turn to page 44.

CHRIS WHEELER

CONTENTS

COSMOS 95 JUNE–AUGUST 2022

FEATURES



32 **HEAVYWEIGHT PARTICLE**
A new, super-accurate measurement of the W boson has rocked physics. **MARTIN WHITE** asks: is the Standard Model broken a little, or a lot?

40 **SOFTWARE WITH A HEART**
Is it possible to make software that takes humanity's diversity into account? **BRON WILLIS** visits the Australian researchers in their world-first lab who think they know how to fix it.

44 **MODEL OR MONSTER?**
Just because we know how to edit genes doesn't necessarily mean we should. But what if a bit of CRISPR Cas9 work is the only hope of saving a species from extinction? **AMALYAH HART** investigates.

56 **ISOLATION**
Feeling lonely is more than a passing thing. **PAUL BIEGLER** reports on the research that's teaching us that it affects us profoundly and chemically – right down to the cells.

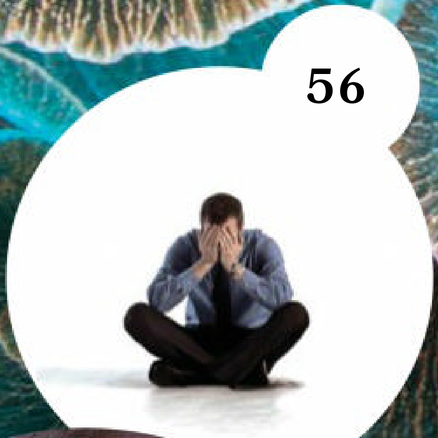
64 **WILDLIFE, WILD AND FREE**
From Antarctic water to Kenyan savannah, stunning images from the 2021 World Nature Photography Awards.

72 **AI AND AUTONOMY**
There's plenty to celebrate about the possibility of driverless cars – and a fair bit to be worried about. **TOBY WALSH** argues the case for and against.

78 **OUR ANCIENT MAMMAL MYSTERY**
Deep-time platypus, gingkos and gum, and *lots* of chocolate. **KEN EASTWOOD** talks to the researchers connecting the dots of the mysterious monotreme family tree.

86 **THE SCIENCE OF SUCCESS**
Surely there are clear reasons – to do with talent and dedication – that explain success? As **ANNAMARIA TALAS** discovers, it's not so easy.

90 **THE ART OF LOGICAL THINKING**
And. Or. If … then. They're simple words, but taken into the mathematical discipline of logic, they've created our digital world. **ROBYN ARIANRHOD** explains the path from Boole to binary.



GABRIEL BARATHIEU

REGULARS

8 DIGEST
Dispatches from the world of science
- JWST first images 8
- Focus: fungi 12
- Tyrannosaur types 16
- Guess the object 21

28 NEXT BIG THINGS
MICHAEL WESTAWAY's *Dark Emu* hypothesis.
GRETCHEN BENEDIX's school of rocks.

ZEITGEIST

100 ENGINEERING'S QUANTUM WALL
JAMIE SEIDEL ponders the time when engineering conviction will meet quantum uncertainty.

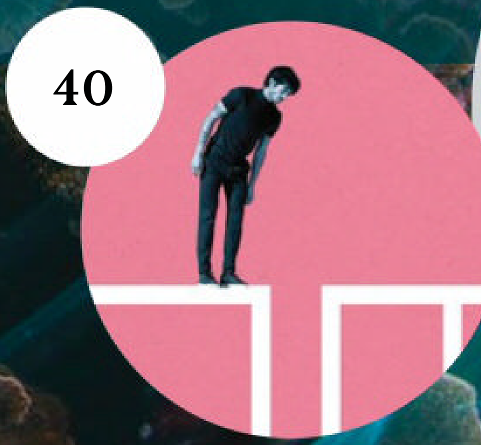
104 SCIENCE OF THE SAUSAGE SIZZLE
ELLEN PHIDDIAN goes under the skin of an Aussie favourite.

108 QUESTIONS AND ANSWERS
The *Cosmos* brains-trust answers readers' curliest scientific questions.

112 MINDGAMES
Fiendishly fun puzzles.

114 PORTRAIT
Mammologist **DAVID HAMILTON**.

Taking out bronze in the Nature Art category of the 2021 World Nature Photography Awards, photographer Gabriel Barathieu from Mayotte explored an intriguing new perspective on these vibrant blooms of lettuce coral in the Raja Ampat archipelago, Indonesia. For more winners from the awards, turn to page 64.



From the Greenlight Editor

WHEN YOU LIVE IN REGIONAL AUSTRALIA, you live with science. You see it in the adaptation of animals to the climate, in the technology used on farms, and in the smart ways people address challenges. You see science in its purest and most practical forms.

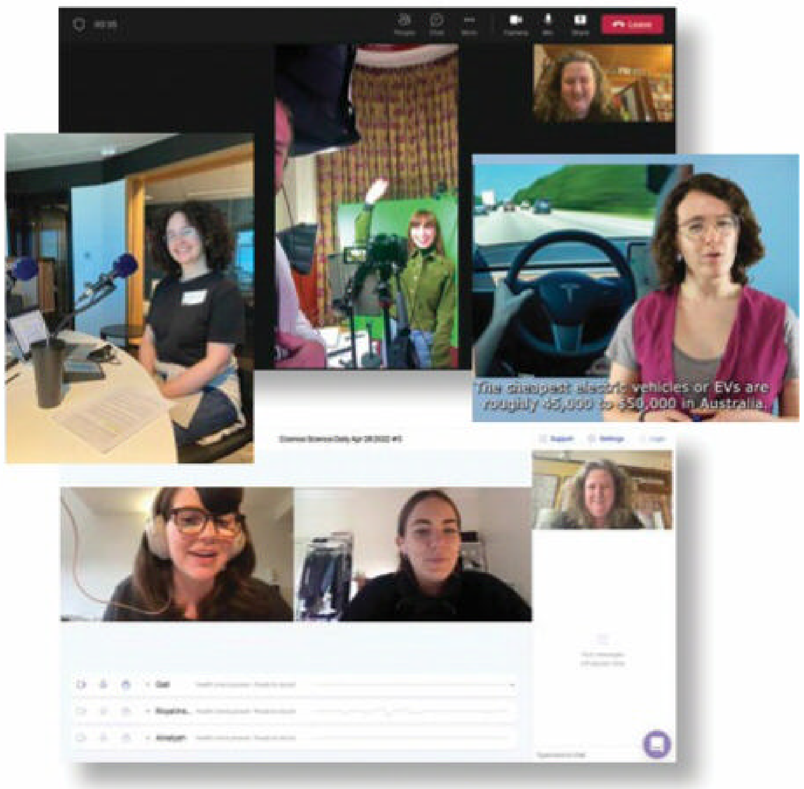
Even on our small farm in Gunnedah, New South Wales, we're also seeing the impact of climate change. Our first summer here was in the searing heat of 2013, when koalas fell dead and lay at the base of trees. Then there was the drought, followed by floods.

So I'm thrilled, along with a small team of journalists, to have the opportunity to write stories about how regional Australia is using science and technology to face the challenges of the climate crisis. The Cosmos Greenlight Project is an opportunity to highlight adaptations from the small and simple through to ideas that could be implemented around the globe. Will every idea, every brave initiative we report on succeed? It's hard to imagine so. But that's one of the things that's great about the bush – people have a crack.

Regional Australia has so much to lose and so much to gain in coming years. There certainly are innovations at work here that have the potential to smooth the road to zero emissions.

The Greenlight Project will focus on the stories of agriculture, industry, energy and First Nations people, and reveal just how important regional Australia's role is in reshaping the way we live.

MARIE LOW, Co-ordinating Editor, Cosmos Greenlight Project


The cheapest electric vehicles or EVs are roughly $45,000 to $50,000 in Australia.

Look and listen

Speaking of change, it's been a busy autumn for our newsroom as we find news ways to communicate science into the wider world. Our newsroom and its journalists celebrated the launch of the Huh? Science Explained *podcasts on SCA's LiSTNR platform (Imma Perfetto in the studio, centre left), we've been making a series of short films explaining some key science and climate issues – as well as the cool stuff (and (including Matilda Handsley-Davis, top, and Ellen Phiddian, centre right) . All this and our daily* Cosmos Briefing *newscasts continue (Amalyah Hart talks to Sophie Calabretto, bottom). We'd love to hear what you think.*

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From the Editors

PEOPLE SEEM TO LOVE CHANGE or to hate it – it's a quality that most definitely lacks middle ground. We're declaring ourselves value-neutral on the matter in introducing this issue as one themed on change – after all, not every change is for the better.

The impact of one change – the re-measurement of the W boson – may not be certain for years, but as particle physicist Martin White points out, it's the strongest shake yet to the Standard Model and holds tantalising promise of a future change to what we know about physics.

Wouldn't it be great if you could change the outcome for species that are threatened with extinction? Well, if your method involves synthetic biology, it's not as easy an answer as it seems. What are the ethics of re-introducing a gene-engineered plant or animal to a wild that has, for better or worse, already marked the organism as an evolutionary dead end?

Some changes aren't so great, as Paul Biegler's story about isolation reveals. Research is drilling down to the physiological changes wrought by loneliness – important work when one considers the separation we've all suffered since COVID jumped into our lives.

Also this issue, Annamaria Talas reveals the science of success; Ken Eastwood looks at the changed landscape of monotreme origins; Robyn Arianrhod considers the importance of logic to the rise of computers; and Bron Willis takes us inside the new HumanISE lab at Monash University, which aims to change how and why we make software.

It isn't necessarily science's role to create change, but change is sometimes the result of scientific investigation. If you believe that a world built on evidence derived from patient research is far, far better than one with much shakier foundations, it would seem to follow that you at least have to *embrace* change – whether you love it or not.

GAIL MACCALLUM Editor
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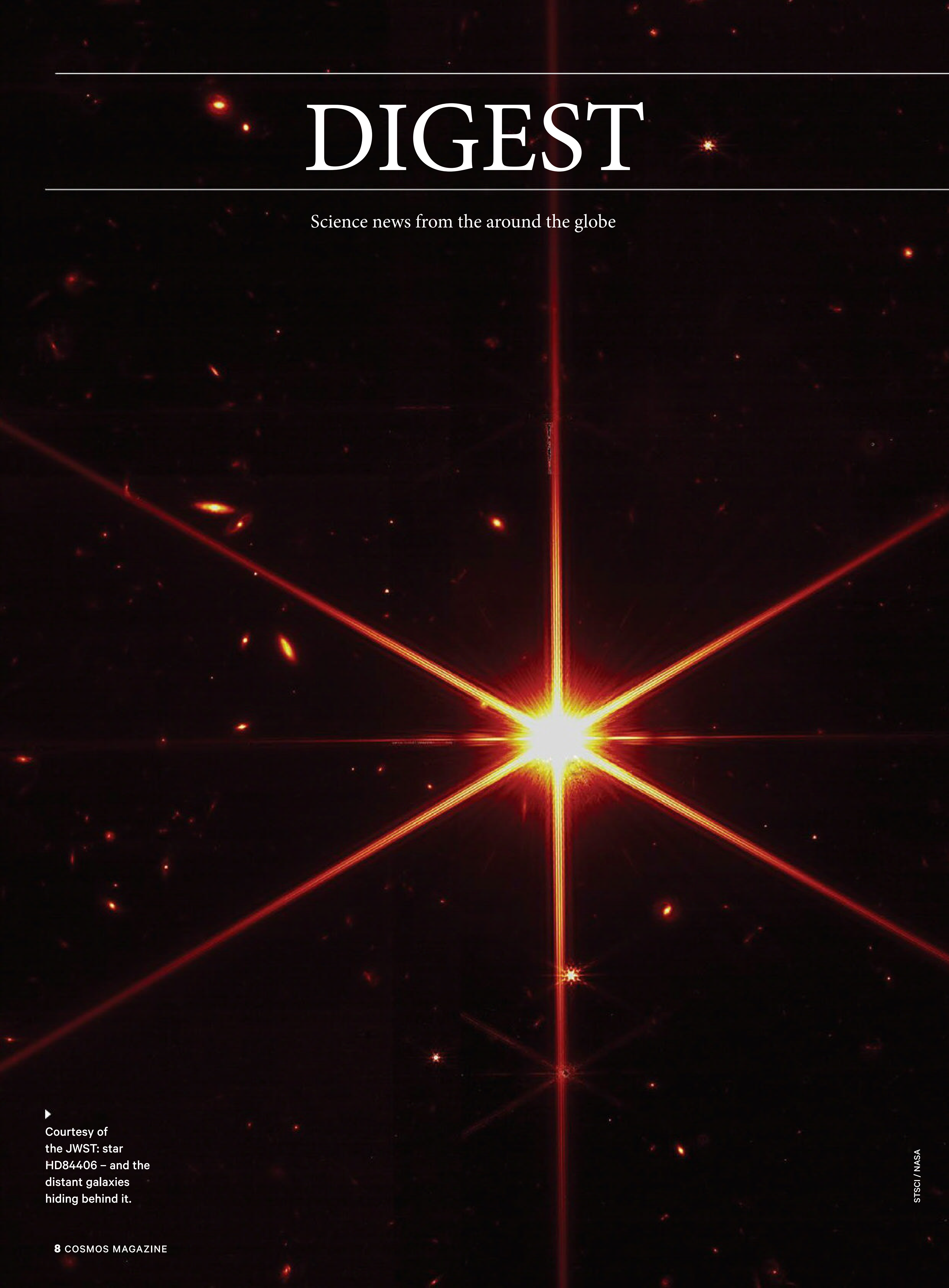
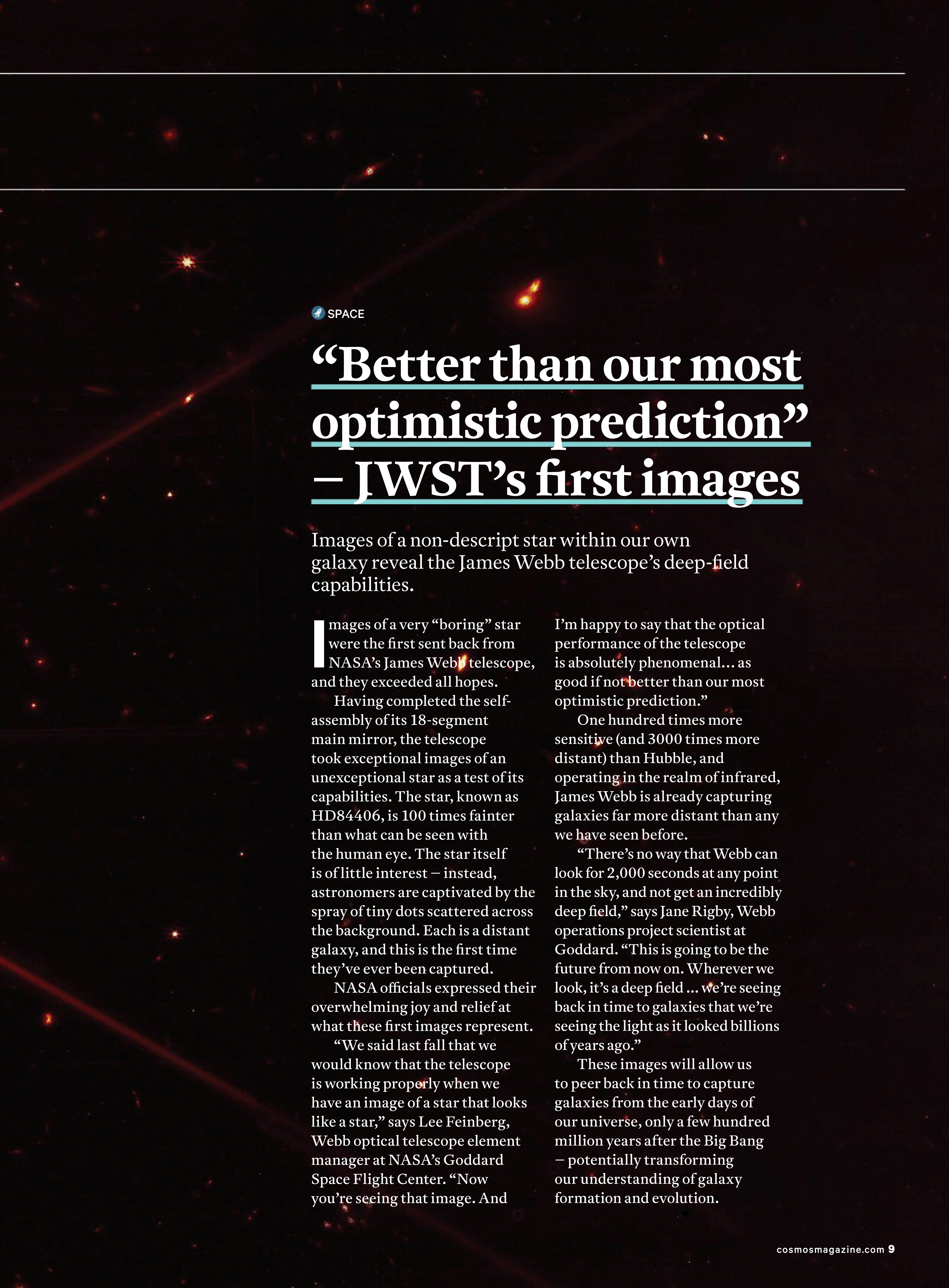
DIGEST

Science news from the around the globe



Courtesy of the JWST: star HD84406 – and the distant galaxies hiding behind it.

STSCI / NASA



SPACE

“Better than our most optimistic prediction” – JWST’s first images

Images of a non-descript star within our own galaxy reveal the James Webb telescope’s deep-field capabilities.

Images of a very “boring” star were the first sent back from NASA’s James Webb telescope, and they exceeded all hopes.

Having completed the self-assembly of its 18-segment main mirror, the telescope took exceptional images of an unexceptional star as a test of its capabilities. The star, known as HD84406, is 100 times fainter than what can be seen with the human eye. The star itself is of little interest – instead, astronomers are captivated by the spray of tiny dots scattered across the background. Each is a distant galaxy, and this is the first time they’ve ever been captured.

NASA officials expressed their overwhelming joy and relief at what these first images represent.

“We said last fall that we would know that the telescope is working properly when we have an image of a star that looks like a star,” says Lee Feinberg, Webb optical telescope element manager at NASA’s Goddard Space Flight Center. “Now you’re seeing that image. And I’m happy to say that the optical performance of the telescope is absolutely phenomenal… as good if not better than our most optimistic prediction.”

One hundred times more sensitive (and 3000 times more distant) than Hubble, and operating in the realm of infrared, James Webb is already capturing galaxies far more distant than any we have seen before.

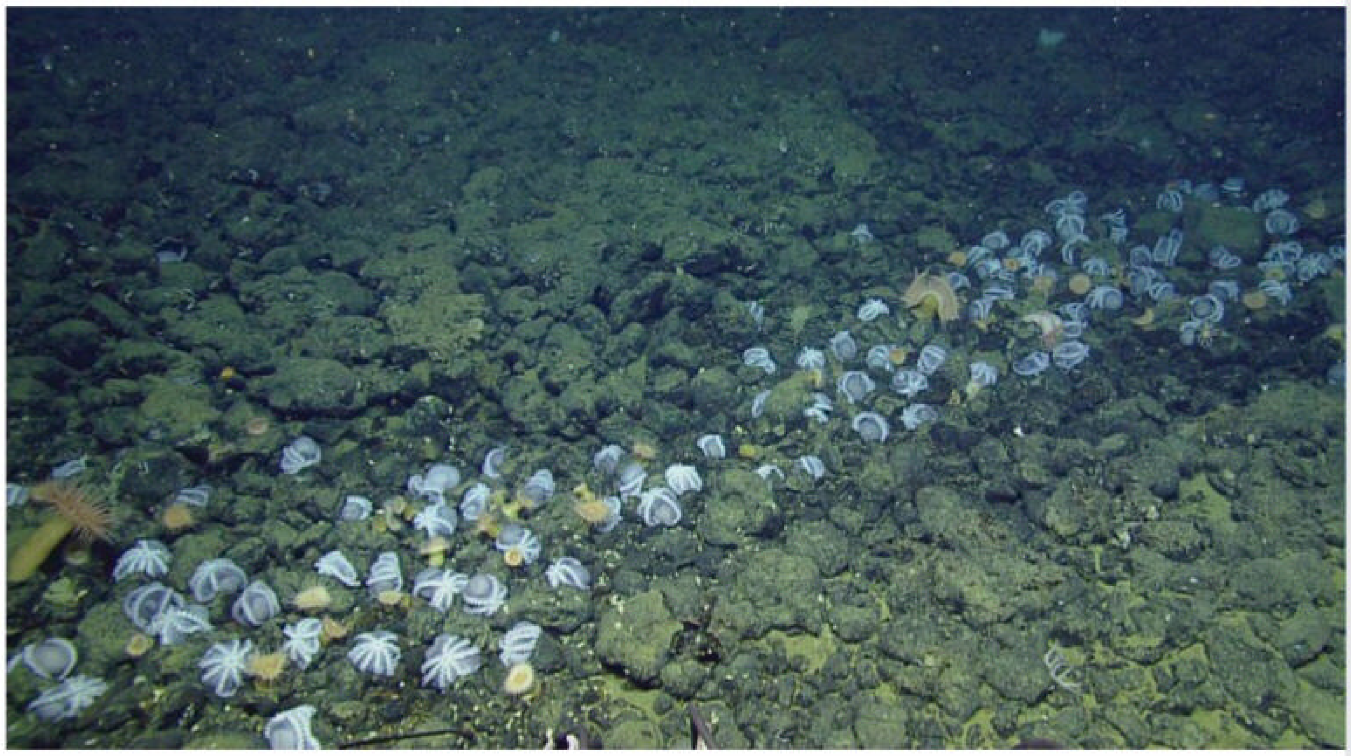
“There’s no way that Webb can look for 2,000 seconds at any point in the sky, and not get an incredibly deep field,” says Jane Rigby, Webb operations project scientist at Goddard. “This is going to be the future from now on. Wherever we look, it’s a deep field … we’re seeing back in time to galaxies that we’re seeing the light as it looked billions of years ago.”

These images will allow us to peer back in time to capture galaxies from the early days of our universe, only a few hundred million years after the Big Bang – potentially transforming our understanding of galaxy formation and evolution.

BIOLOGY

Warming up the underwater brood period

Octopuses may be congregating near warm-water vents to improve their reproductive success.



A massive colony of octopuses (*Muusoctopus robustus*) observed near Davidson Seamount in the Monterey Bay National Marine Sanctuary. These octopuses are likely brooding their eggs: protecting them by inverting their arms and covering them with their body.

OCEAN EXPLORATION TRUST AND THE NATIONAL MARINE SANCTUARY FOUNDATION.

Enormous numbers of deep-sea octopus are congregating around the base of certain seamounts, scientists say.

There are so many, in fact, that a team led by James Barry of the Monterey Bay Aquarium Research Institute, US, counted 7,242 nesting females in a single 2.5 hectare "Octopus Garden," about 120 kilometres offshore from central California.

The octopuses – all of the species *Muusoctopus robustus* – appear to be drawn to warm-water springs at the base of the seamount, which Ann Hartwell, a PhD candidate at the University of New Hampshire, US, says were only discovered in the last 10 years and appear to be very different from the geothermal vents that have long fascinated ocean scientists.

Those vents are super-hot, while the newly discovered ones are merely warm, raising the water temperature by at most 10°C, according to Hartwell.

Why octopuses are drawn to these warm springs was initially a mystery. But Barry thinks it's because the warmth helps them reproduce more effectively.

At the depths of the Octopus Garden, 3200m below sea level, the normal temperature is 1.6°C, he says. That's an issue for octopus reproduction, because studies have shown that the time needed for octopus eggs to develop and hatch is extremely long. It is also dramatically affected by water temperature. At 5°C their brood period is around 600 days. At 1.6°C it is likely be pushing close to 14 years.

Barry's team studied 26 nesting females. The water temperature averaged 5.1°C, and brood periods averaged 576 days; no wonder they were drawn to the warmer waters.

ANTHROPOLOGY

FOR NAVIGATIONAL SMARTS, AVOID A GRID-CITY CHILDHOOD

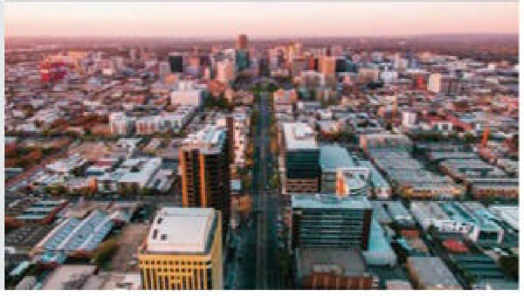
Research suggests that people who grow up in grid-pattern cities are more likely to have a poor sense of direction.

The study shows that people who have spent their childhoods in rural areas have the highest levels of navigation skill. People who grew up in cities with less orderly street plans also performed well in their research. But those from cities based around a planned grid system – think New York or Adelaide – struggled the most to avoid getting lost.

Nearly 400,000 participants from 38 different countries were given a set of wayfinding tasks on a smartphone game called *Sea Hero Quest*, which was designed for research into Alzheimer's disease. Their results were compared against a range of variables.

Professor Hugo Spiers, from University College London, who led the research, explains that participants' poor navigation "seems to be influenced by the lack of complexity of many street networks in cities". The results suggested that their current place of residence had minimal effect.

Researchers also found that navigation skills begin declining in early adulthood.



ARTEMISDIANA / ISTOCK / GETTY IMAGES

MEDICINE

Armour for good bacteria against antibiotics

Genetically engineered probiotic protects the gut microbiome and reduces likelihood of antibiotic resistance spreading.

Good in your guts: a genetically engineered bacterium tested in mice makes the gut microbiome happy.

Researchers of synthetic biology based at the Massachusetts Institute of Technology (MIT) in the US have devised a system to protect the gut microbiome from the effects of antibiotics.

The new study, published in *Nature Biomedical Engineering*, reports on the successful use in mice of a "live biotherapeutic" – a genetically engineered bacterium that produces an enzyme which breaks down antibiotics in the gut.

Antibiotics are hugely important in fighting bacterial infections, but increasing human use of them has contributed to the rise of antibiotic resistance, which has made many bacterial diseases increasingly difficult to successfully treat.

Antibiotic treatment can also kill off bacteria in our resident healthy gut microbiome – the trillions of microbes that live in our gastrointestinal tract and assist with food digestion, immune development and vitamin synthesis.

In some cases, these indiscriminate effects of antibiotics can have life-threatening consequences. In the US, about 15,000 deaths each year are attributed to diarrhoea and colitis (inflammation of the colon) caused by overgrowth of the bacterium *Clostridium difficile* following antibiotic overuse.

The team from MIT began with a strain of the bacterial species *Lactococcus lactis*, which is typically used in cheese production and considered generally safe for human consumption.

The researchers genetically engineered the *L. lactis* strain to produce an enzyme called beta-lactamase, which breaks down beta-lactam antibiotics. Beta-lactams are a class of widely used antibiotics including penicillin, ampicillin and amoxicillin. They currently account for about 60% of the antibiotics prescribed in the US.

To test their invention, they gave mice an injection of ampicillin as well as two oral doses of engineered *L. lactis*. They showed that the L. lactis successfully produced beta-lactamase and degraded the ampicillin in the mouse gut, without reducing the levels of ampicillin in the blood.

"This work shows that synthetic biology can be harnessed to create a new class of engineered therapeutics for reducing the adverse effects of antibiotics," says the paper's senior author, James Collins.

FOCUS: FUNGI

01

Researchers have used a fungus called *Rhizopus delemar*, found on supermarket bread, to make a sustainable, biodegradable fabric that behaves exactly like leather.

02

The island of Mo'orea, in French Polynesia, is home to a treasure trove of fungi – a recent trip to the island yielded over 200 species previously unknown to science.

03

The tawny crazy ant, which is invasive to the US, could be controlled with a naturally occurring fungus.

04

Just as bacteria can become resistant to antibiotics, fungus can grow resistant to antifungals. We're seeing this now with the lung infection aspergillosis.

05

Researchers have found at least 600 genes from bacteria, fungi and viruses that have appeared in plant genomes from horizontal gene transfer.

06

Coating seeds with "melanised endophytic fungi" can enhance a plant's ability to suck up CO_2 from the atmosphere and store it in soil.

07

Megafires affect forest-friendly fungi communities by reducing diversity and soil make-up, creating further difficulties for post-fire recovery.

www.cosmosmagazine.com/ **01** technology/materials/sustainable-textiles-fungi/ **02** nature/plants/mooreas-new-fungi-biodiversity/ **03** nature/animals/fungus-fight-crazy-ants/ **04** health/medicine/drug-resistant-aspergillosis/ **05** nature/evolution/microbes-transferred-genes-to-ancient-plants-to-help-them-evolve-on-land/ **06** earth/climate/soil-fungi-could-help-us-with-global-warming/ **07** science/biology/megafire-microbes/

ALAN ROCKEFELLER

ARCHAEOLOGY

THE VENUS OF WILLENDORF'S LONG JOURNEY

Researchers pin the statuette's origin to Italy or Ukraine.

The Venus of Willendorf, one of the world's oldest pieces of artwork, was made of oolite rock mined in Italy, more than 600 kilometres from her final resting place in Austria, according to new research.

Gerhard Weber at the University of Vienna used micro-computed tomography to obtain high-resolution images of the stone's internal structure, to determine the stone's place of origin.

With the help of geologists Alexander Lukeneder and Mathias Harzhauser of the Natural History Museum Vienna, the researchers searched for oolite deposits in Europe and sampled them for comparison, covering an area stretching from France to Ukraine.

While the statue resembles contemporary Ukrainian art and tools, statistical analysis of numerous specimens yielded a telltale close match to a deposit in northern Italy, near Lake Garda.

LOIS LAMMERHUBER; HYDRA MARINE SCIENCES GMBH.

ENVIRONMENT

Seagrass meadows store much more carbon than previously realised

Sweet secrets of seagrass ecosystems revealed in new study.

A team of marine microbiologists has investigated how carbon is stored and cycled through the seagrass ecosystem, with some surprising results.

Research published in *Nature Ecology & Evolution* reveals that seagrass ecosystems store a surprising amount of carbon in the form of sucrose.

The study found that sugar concentrations in the seagrass rhizosphere were about 80 times higher than previous marine records.

"To put this into perspective, we estimate that worldwide there are between 0.6 and 1.3 million tonnes of sugar, mainly in the form of sucrose, in the seagrass rhizosphere," says senior author Manuel Liebeke, head of the metabolic interactions research group at the Max Planck Institute for Marine Microbiology in Germany, and senior author on the paper.

"That is roughly comparable to the amount of sugar in 32 billion cans of Coke!"

The team estimated that if the amount of sucrose present in the seagrass rhizosphere were metabolised by microbes, at least 1.54 million tons of carbon dioxide would be released into the atmosphere.

"That's roughly equivalent to the amount of carbon dioxide emitted by 330,000 cars in a year," says Liebeke.

TECHNOLOGY

BirdBot gets a walk-up start

Robot demonstrates that avian-inspired gait is energy efficient and beautifully balanced.

Apparently emus – and ostriches – represent the pinnacle of evolutionary achievement.

Their legs seem to be backwards, with knees bent in the opposite direction to ours. And, as their lower leg swings forward, their foot flops down. Turns out, it's a technique that's extremely mechanically efficient.

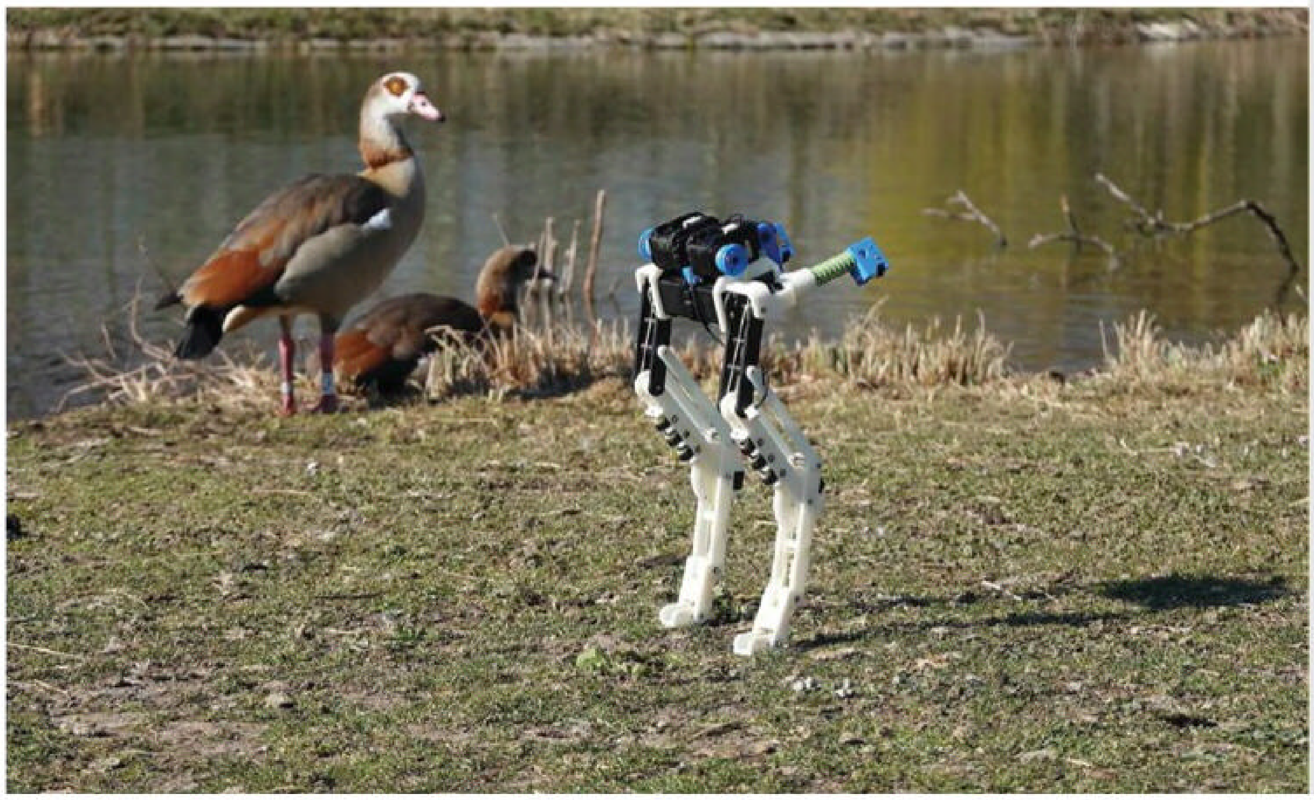
Dozens of bipedal robot designs continue to teeter about testing sites after decades of research. Their heavy metal bodies are studded with motors, actuators and gears. Software algorithms are still struggling to coordinate everything for basics such as balance and motion.

Now the Max Planck Institute for Intelligent Systems and the University of California, Irvine have developed a bird-leg inspired robotic mobility system 300 times more energy efficient, and far easier to balance.

Instead of motors, they've applied a network of artificial muscles and springs. The 'muscles' are primed when the leg is pressed into the ground and placed under load, releasing their mechanical spring energy as the leg straightens to move forward.

Only two motors are needed: One in the hips to get the legs swinging, the other is in the knee to lift the leg. The rest of the walking action is purely the result of the leg's shape combined with the tendon-like effect of cables and pulleys.

The system has many benefits, say the researchers in *Science Robotics*. Not only do the tendons return energy to the system, the natural mechanical motion dramatically reduces the computing power needed to control its movements and balance.



TECHNOLOGY

WOULD YOU WEAR A T-SHIRT THAT COULD LISTEN TO YOU?

Futuristic fabrics might let your clothes eavesdrop on you.

Researchers from the Massachusetts Institute of Technology, US, have created fabrics that can 'hear' sounds.

Publishing in *Nature*, they describe their fabric yarn interwoven with an electrical, or 'piezoelectric' fibre. The resulting fabric uses a mechanism similar to the tympanic membrane: the fabric converts pressure waves at audible frequencies into mechanical vibrations which can be processed into electrical signals.

Only a small quantity of the fibre is needed to make fabric acoustically sensitive. Researchers say garments could be useful for police officers to narrow down the direction of a gunshot, for people with hearing aids to listen in specific directions while removing background noise, or even as a wearable stethoscope.

All this, and the fabric is able to withstand being chucked in the washing machine at the end of a long day of listening.

SCIENCE ROBOTICS; SOL VAZQUEZ CANTERO / EYEEM / GETTY

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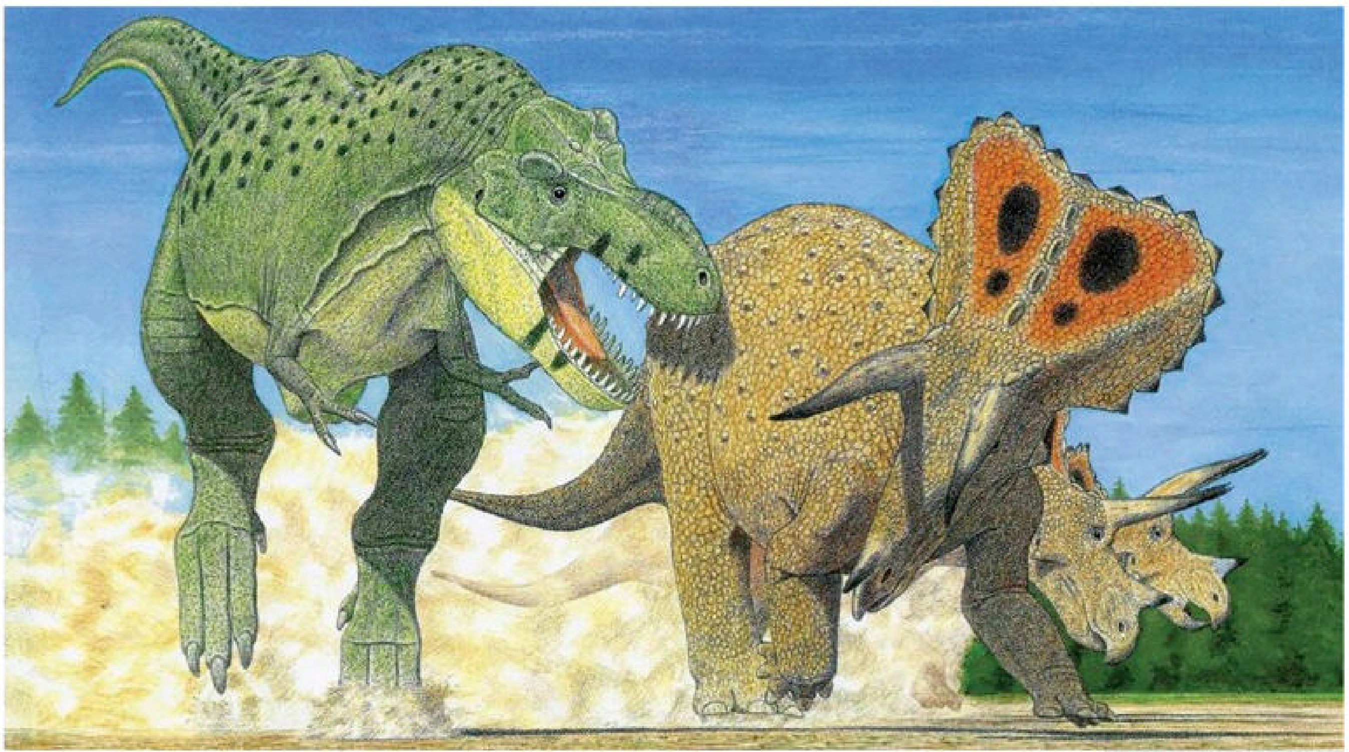
PALAEONTOLOGY

Tyrant Lizard Emperor, King, and Queen: T-rex might be three species

New analysis of old bones suggests it's time make way for more members of the dinosaur royal family.



▲ *Tyrannosaurus imperator* attacks a herd of the contemporary *Triceratops horridus.*

GREGORY S. PAUL

Everyone loves a new dinosaur. But what if there were new species hiding right under our noses?

Taking a close look at collections of Tyrannosaurus fossils, researchers from the College of Charleston, US, believe that we've been unwittingly lumping three closely related species of this most famous dinosaur into the one basket, and that it's time to recognise not just the tyrant lizard king, but the queen and emperor too.

Publishing in *Evolutionary Biology*, the researchers examined physical differences in the femur and dental structures of 37 Tyrannosaurus specimens, and claim that the variation in morphologies doesn't fit with patterns expected through mere sex differences.

The authors used measures of the length and circumference of the femur bones to calculate their robustness, finding a distinct split between specimens with more robust or more gracile bones. The two femur types weren't evenly split across the collection of specimens, suggesting they weren't associated with sex. They also didn't correlate with overall size – juveniles presented with the same discrepancies in femur thickness as adults.

Tyrannosaurus teeth also held clues – some had two slender incisor teeth on each side of the front end of the jaw, while others had only one. Only 12 of the studied specimens had both femur and teeth present, but this limited dataset nonetheless suggested that a single incisor tooth correlates with more gracile bones.

As final corroboration, the authors fit their findings to a geological timeline. Of the 37 specimens studied, 29 were unearthed in the Lancian upper Maastrichtian formations in North America, in sediments dating to between 67.5 and 66 million years ago. The distinctly banded sediment layers at this fossil site allowed researchers to arrange their specimens chronologically, with those found in the lowest layers representing the most ancient of the collection.

Importantly, the more gracile femurs were entirely absent from the lower layers. Instead, the femurs in this layer showed only the normal degree of variation that is expected in any population. The researchers believe that at the time these lower layers of sediment were deposited, only a single Tyrannosaurus species roamed the Earth.

The first gracile femur makes its appearance in the middle layer, followed by five in the upper layer. In these most recent layers, the level of variation in these bones is no longer within the bounds of normal population differences, instead painting a picture of the emergence of distinct body forms, or "morphotypes".

"We propose that the changes in the femur may have evolved over time from a common ancestor who displayed more robust femurs to become more gracile in later species," says Gregory Paul, lead author and palaeoartist. "The differences in femur robustness across layers of sediment may be considered distinct enough that the specimens could potentially be considered separate species."

BIOLOGY

HOT POTATO NEWS

Surprisingly complex potato genome finally sequenced.

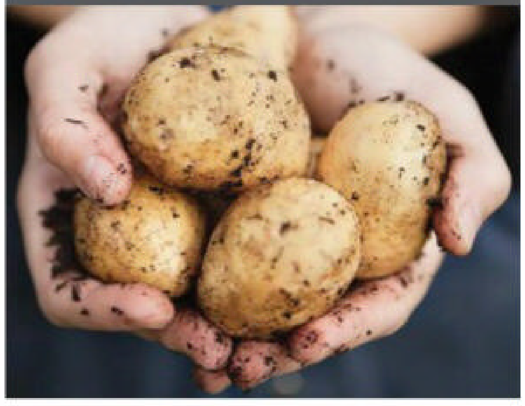
A research team from Germany and China has announced the first sequencing and assembly of a potato genome.

Potatoes have a tetraploid genome – they have four copies of each chromosome, two copies inherited from each plant parent. Four copies of each chromosome means four copies of each gene, presenting some difficulty for those seeking to peek under the potato's genetic jacket.

The research team developed a clever approach to circumvent this problem and successfully reconstruct the potato genome, focussing their effort on the plant's reproductive pollen cells.

Because sex cells fuse together to create offspring, pollen contains half as many chromosome copies as the other cells. In humans, sperm and egg cells have only one copy of each chromosome, with the offspring ending up with two copies. For the potato, the pollen cells contain only two copies of each chromosome, rather than four.

Sequencing the pollen cells, the research team reduced the complexity of the data to the point that they could reconstruct the entire potato genome.

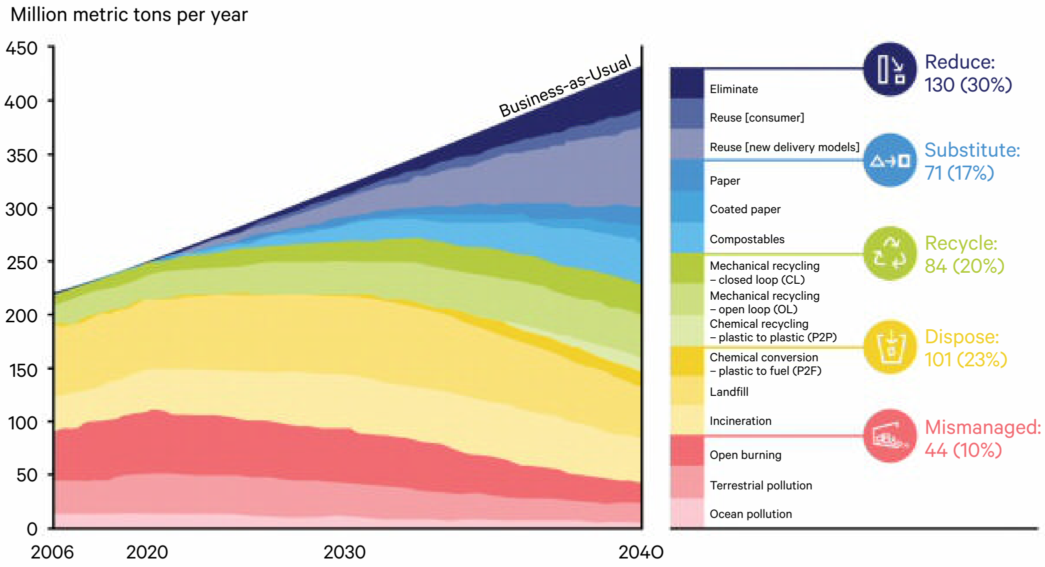


BROWNIE HARRIS/GETTY IMAGES, MODIFIED FROM LAU ET AL. 2020/SCIENCE.

EARTH

Experts use model to offer radical solution to plastic waste: don't reduce – just stop

Even reduction measures won't stop alarming plastic pollution increase.



Back in the distant days of 2017, about 4.9 billion tonnes of plastic existed on the planet. Now, Earth has 8.3 billion tonnes of plastic waste, with around 11 million tonnes running into the ocean each year. By 2040, this number is estimated to almost double.

While many different solutions have been developed to help reduce or process our plastic waste (including bioplastics, plastic-eating caterpillars, and robot arms to do the soft-plastic recycling) an international group of scientists say this is no longer enough. In a letter to *Science*, they argue that the best way to tackle this issue is to phase out production of plastics completely.

Melanie Bergmann of the Alfred Wegener Institute, in Germany, was the initiator of the letter. "Even if we recycled better and tried to manage the waste as much as we can, we would still release more than 17 million tonnes of plastic per year into nature," says Bergmann. "If production just keeps growing and growing, we will be faced with a truly Sisyphean task."

Modelling shows that even if we immediately implement all feasible interventions – such as reducing, substituting or recycling plastic waste – 6.5 billion tonnes of plastic waste will still be produced by 2040, with over 700 million tonnes ending up in the environment.

BIOLOGY

Sandy the pure desert dingo

International collaboration of researchers sequence the genome of the pure desert dingo.

Last year, it was revealed that dingoes (*Canis lupus dingo*) in Australia have pure ancestry and that there is little interbreeding with domestic dogs – just 0.6%.

As of April, the full genetic sequence of Sandy Maliki, a wild-born pure Australian desert dingo has been published, in *Science Advances*. Led by researchers at La Trobe University, including dingo advocate Professor Bill Ballard, this international collaborative effort has confirmed that pure dingoes are intermediate between wolves (*Canis lupus*) and domestic dog breeds (*Canis lupus familiaris*).

Sandy Maliki was discovered in 2014 as a three-week-old pup near the Strzelecki Track in the central Australia desert, along with her sister and brother. Sandy drew worldwide attention when she won the World's Most Interesting Genome competition in 2017.

Scientists have lined up Sandy's genome against a Greenland wolf (*Canis lupus orion*), five domestic dog breeds including the German shepherd, and the oldest known dog breed, the Basenji, which originated in Africa.

A previous study looking at single nucleotides of DNA (known as SNPs) placed dingoes as sisters to the Akita and chow chow, with the Basenji between this group and the wolf. However, with the whole genome sequenced, the relationship of the dingo to domestic and ancestral canine lineages can finally be resolved.

From this research, we are also able to gain insight into the desert dingo's biology. For example, the number of copies of a pancreatic 'amylase' gene can assist understanding of its dietary adaptations.

Sandy the pure desert dingo at three weeks of age.

"A pure dingo has only one copy of the amylase gene, whereas domestic dogs have multiple copies – which we show influences the gut microbiome and, we predict, affects what dingoes eat," says Ballard. "Based on this new knowledge, we hypothesise that dingoes are far less likely to eat farm animals, including sheep. If we're correct, what farmers currently assume are dingoes killing their stock, are likely to be feral wild dogs."

This five-year study was a culmination of research undertaken by experts in microbiology, computational biology and veterinary science, from 10 institutions across six countries including Australia, Denmark, Norway, Germany, USA and England, and is a huge step forward in the preservation of this native keystone species.

JULIE FLETCHER / MOMENT / GETTY; BARRY EGGLETON / UNSW

EDUCATION
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Astronomers discover a sideways black hole

New finding calls theories of black hole formation into question.

An international team of researchers have made a surprising astronomical discovery: a black hole that spins on its side.

A paper published in *Science* details the new finding, which the researchers say challenges current theories about black hole formation.

The study focused on a black hole found in an x-ray binary system called MAXI J1820+070. Such systems are formed when a massive star in a binary star system collapses to form a black hole.

The black hole pulls matter away from the remaining, lighter companion star, leaving traces in the form of both optical radiation and x-rays – hence the name.

The scientists used an instrument called an astronomical polarimeter to measure the orbital axis of the MAXI J1820+070 system, and compared these measurements to existing knowledge about the black hole's spin.

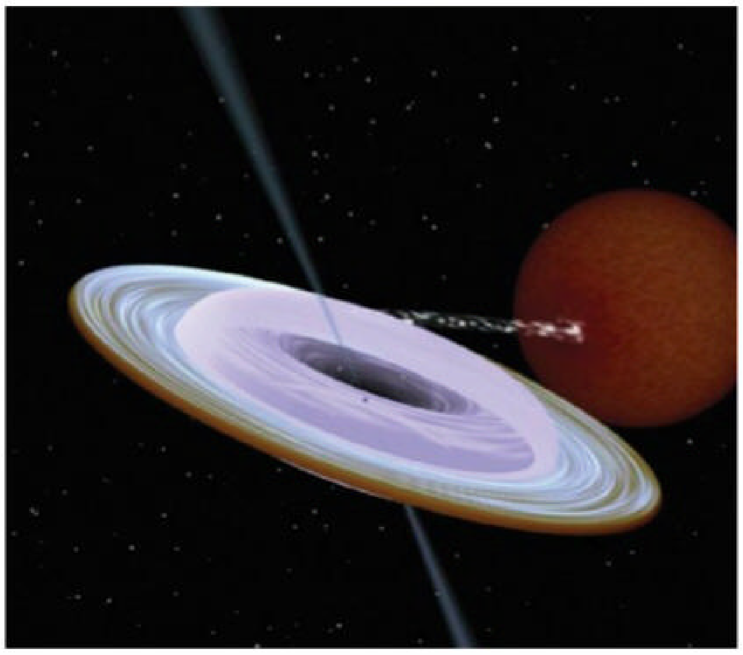
The polarimeter, named DIPol-UF, was built by the Leibniz Institute for Solar Physics (KIS) at the University of Freiburg in Germany and by the University of Turku in Finland.

"DIPol-UF is unique in its ability to measure optical polarisation with the precision and accuracy of a few parts per million," says author Svetlana Berdyugina, a professor in astrophysics at the University of Freiburg and director of KIS.

"Determining the orbital orientation of black holes based on polarisation opens a new path to understanding their formation and physics."

The measurements showed that the rotation axis of the black hole in MAXI J1820+070 was

An artist's impression of the x-ray binary system MAXI J1820+070 containing a black hole (small black dot at the center of the gaseous disc) and a companion star (red). A narrow jet is directed along the black hole spin axis, which is strongly misaligned from the axis of the orbit.



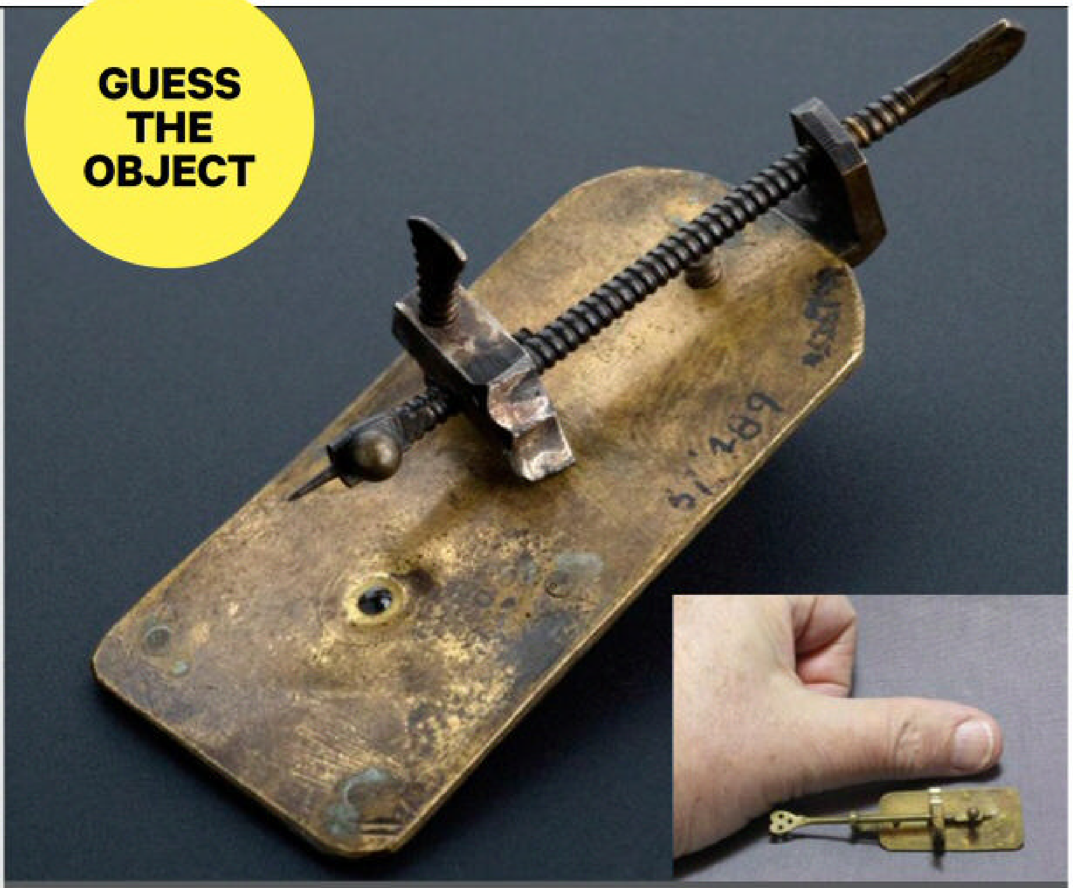
tilted at more than 40 degrees from the system's orbital axis, a result that Berdyugina describes as "completely unexpected".

"Scientists have often assumed that this difference is very small when modelling the behaviour of matter in a curved period around a black hole," she says.

This assumption is challenged by the discovery of such a large difference in angles, with implications for the broader study of x-ray binary systems.

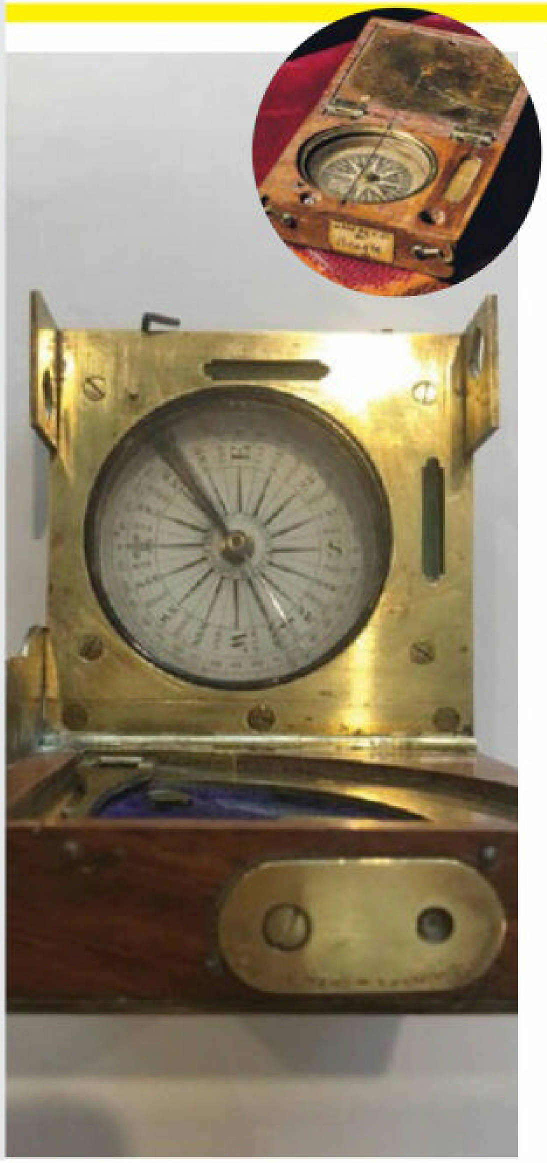
R. HYNES. LONDON SCIENCE MUSEUM. MICROSCOPE ANTIQUES

GUESS THE OBJECT



SMALL WONDER

After last issue's contribution, we're delighted by a second reader-directed entry from Matthew Hunt, aka 'Matt in Brissy'. (This time we know what it is!) This elegant little device was made in the 17th or early 18th century. It performs a job well known to science (and indeed to the wider community) but very simply and effectively. Very few of these objects survive to modern times and their place in the development of scientific technology – and knowledge – is profound. Crackerjack suggestion, Matt. We know you can Google, but where's the fun in that? The correct answer – and/or the most creative – will be published in the next issue. Send your hunches to contribute@cosmosmagazine.com



We said it'd be fun, right? Rodney Bartlett thought it was a replica of an early device for determining longitude at sea; 11-year-old Henry Standish guessed an "old geological survey compass" (a view endorsed by Garth Powell). Lana's tongue-in-cheek suggestion of a "bore sight for a fougasse" sent us scurrying for our history books. But Mark Dale not only identified it as a surveying compass clinometer, but backed his claim with a picture of a similar-looking object used by Charles Darwin (inset). "I have a modern equivalent," he explained. "It's a prismatic type compass and incorporates a small inclinometer. These instruments are used by geologists in the field to establish the dip (inclinometer) and strike (compass) of the tilted beds of sedimentary rocks." Honourable mentions go to Riley Biggs, Laurance Papale and Steph Baker, all of whom mailed in the same answer as Mark in the days after.

SUSTAINABILITY

Printable polymers for (future) biodegradable batteries

Researchers inch towards a biodegradable way to power small devices.

What if, instead of a rigid chunk of lithium-ion, your phone was charged by a flexible, printable battery? And what if that battery were biodegradable?

According to a group of Australian and Chinese researchers, this is possible with technology they're working on. Such batteries would probably only ever be powerful enough to charge small devices but, at least in the lab, they're rivalling lithium-ion at the small scale.

The research revolves around organic radical batteries, or ORBs. These batteries rely on a carbon-containing polymer to store and transport electrons. They don't require any metals to make, so while the materials aren't currently biodegradable, it should be possible to create them from a biodegradable material.

ORBs aren't a new concept, but so far several features are inferior to commercial batteries, according to Dr Zhongfan Jia, a researcher in chemistry at Flinders University in Adelaide.

The first is the batteries' voltage: the force with which they can discharge power.

The next problem is capacity – what we might think of as storage. "Capacity is how much energy you can put in," says Jia.

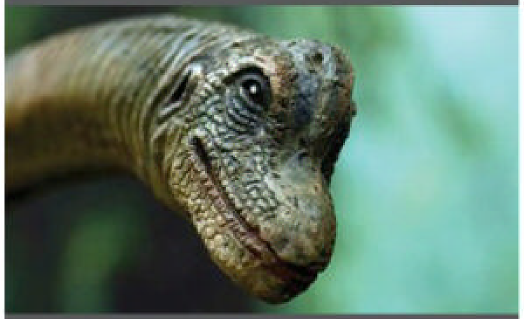
The third issue is power density."If you have a fancy racing car, it might be accelerated from 0 to 100 km/h within six or seven seconds. That difference is related to the power density," says Jia.

Jia and colleagues have found a catalyst that allows these batteries to compete with lithium-ion in both voltage and storage capacity.

In *Chemical Engineering Journal*, they described a prototype battery with a voltage of 2.8 V – one of the highest voltages ever reported in an ORB.

PALAEONTOLOGY

WHAT WOULD IT FEEL LIKE TO PAT A DINOSAUR?



New laser imaging study gets us a step closer to answering this essential question.

Palaeontologists have used laser imaging on a rock found in England in 1852 to reveal on its surface fine scales and "goosebump-like structures" called papillae on dinosaur skin.

The papillae, which have also been observed in other sauropod species, would reportedly have given the skin a "fine bumpy texture".

The scientists suggest the 'goosebumps' may have helped the large, long-necked sauropods regulate body heat by increasing surface area.

"When you're as large as a sauropod – which can exceed 30 metres in length and 50 tonnes in mass – overheating becomes a real concern simply because you have a comparatively small surface area compared to your volume," says Nathan Enriquez, who co-led the study.

"Sauropods started getting really big in the Early Jurassic, which is about the same time that we predict these skin papillae evolved ... there may be a link between the emergence of these papillae and the evolution of huge sauropod body sizes."

MARYNA TERLETSKA / GETTY IMAGES; DBRSKINNER / GETTY.

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BIOLOGY

MALE BIRTH CONTROL?

A non-hormonal contraceptive shows promise in male mice

A team of researchers from the University of Minnesota have obtained promising results in a trial testing a non-hormonal male contraceptive on mice.

"Scientists have been trying for decades to develop an effective male oral contraceptive," says University of Minnesota, US, researcher Md Abdullah Al Noman.

Most compounds currently undergoing clinical trials target the male sex hormone testosterone, and can produce undesirable side effects like weight gain, depression and increased cholesterol levels.

Researchers targeted a protein called the retinoic acid receptor alpha (RAR-α), a form of vitamin A that plays a key role in cell growth, cell differentiation and embryonic development.

The team synthesised approximately 100 compounds and identified one – YCT529 – that was 99% effective when given to male mice for four weeks. The mice were able to father pups again 4–6 weeks after they stopped receiving the compound.

EARTH

Earth + warming = speedier ocean

Sixty-six million years of geological data suggests heating makes ocean currents stronger.

Ocean currents play a big role in floods, droughts, and other large-scale weather patterns. They're notoriously complicated and there's debate among researchers about how to untangle conflicting sources of information.

Satellite data seems to suggest that ocean currents are, on average, becoming more intense. But satellite data only stretches back about 30 years – so it's hard to be conclusive.

Now those findings have been backed up by several million more years of data, thanks to researchers at the University of Sydney – and some rocks.

"If we think of the long-term evolution of the Earth, either in the past or into the future, then three decades is not a lot," says Dr Adriana Dutkiewicz, geologist at the University of Sydney.

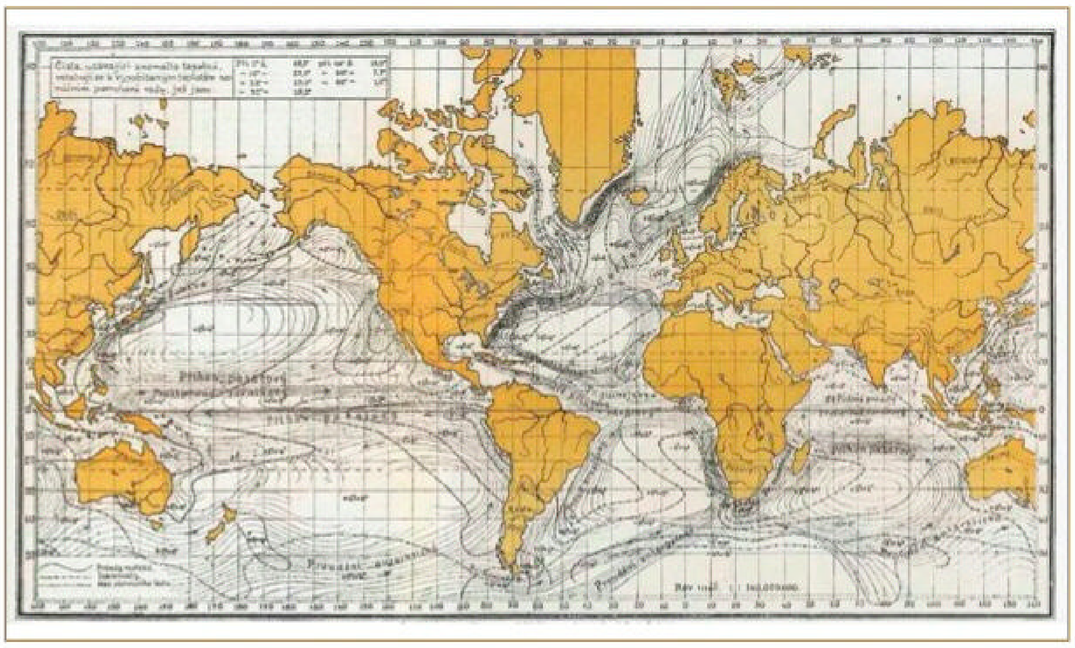
Dutkiewicz, along with colleague Professor Dietmar Müller, went to geological records taken from deep-sea scientific drilling programs, and looked for this longer-term behaviour.

In *Geology*, they examine the gaps, or "hiatuses", in these geological records. If there are more hiatuses, then there are likely some more vigorous deep-ocean currents causing them.

The researchers examined hiatuses from records at 293 global sites. With data stretching back 66 million years, they found an unexpected pattern.

"There were less and less and less hiatuses through time, as the world descended into a more severe ice age over the course of the last 13 million years," Müller says. "Our results, that happen to be consistent with the results from the satellite data over the last few decades [...], suggest that ocean mixing will become more vigorous."

The ocean absorbs much anthropogenic CO_2 and heat, so it's likely that this speeding up will have multiple effects.



ROBERT TREVIS-SMITH/GETTY IMAGES; IMAGE VIA WIKIMEDIA COMMONS

Mammal of the year

At last, an election you can actually get excited to vote about: Australian Mammal of the Year.

What's your favourite Australian mammal? Wombat? Kangaroo? Possum? Or something less known, like a dunnart or a dibbler?

Of course we all love voting in the annual Australian Bird of the Year poll (run by Guardian Australia and BirdLife Australia). For the more botanically inclined, there's Eucalypt Australia's Eucalyptus of the Year as well. But we at Cosmos feel that our feathered and leafy friends have had the spotlight to themselves for a little too long.

Australia is home to incredible mammals. There are over 350 officially described native species in Australia, with the vast majority being endemic: found nowhere else in the world.

Australia is also one of very few places to host all three main branches of the mammalian evolutionary tree: monotremes (think echidnas and platypuses), marsupials (kangaroos and koalas), and placental mammals. They also fulfil a dizzying diversity of ecological niches and roles – from ecosystem-engineering bandicoots to native-plant-pollinating gliders to scavenging Tasmanian devils.

Sadly, Australia also has one of the highest rates of overall biodiversity loss among wealthy countries, and we know that at least 34 mammal species have become extinct since European arrival.

We think Australian mammals deserve a bit of love and attention, so we're launching our **Australian Mammal of the Year** poll. Over the next few months on our website we'll be publishing stories from mammal enthusiasts spruiking their favourite species, sharing amazing facts and endearing characteristics and trying to win your vote.

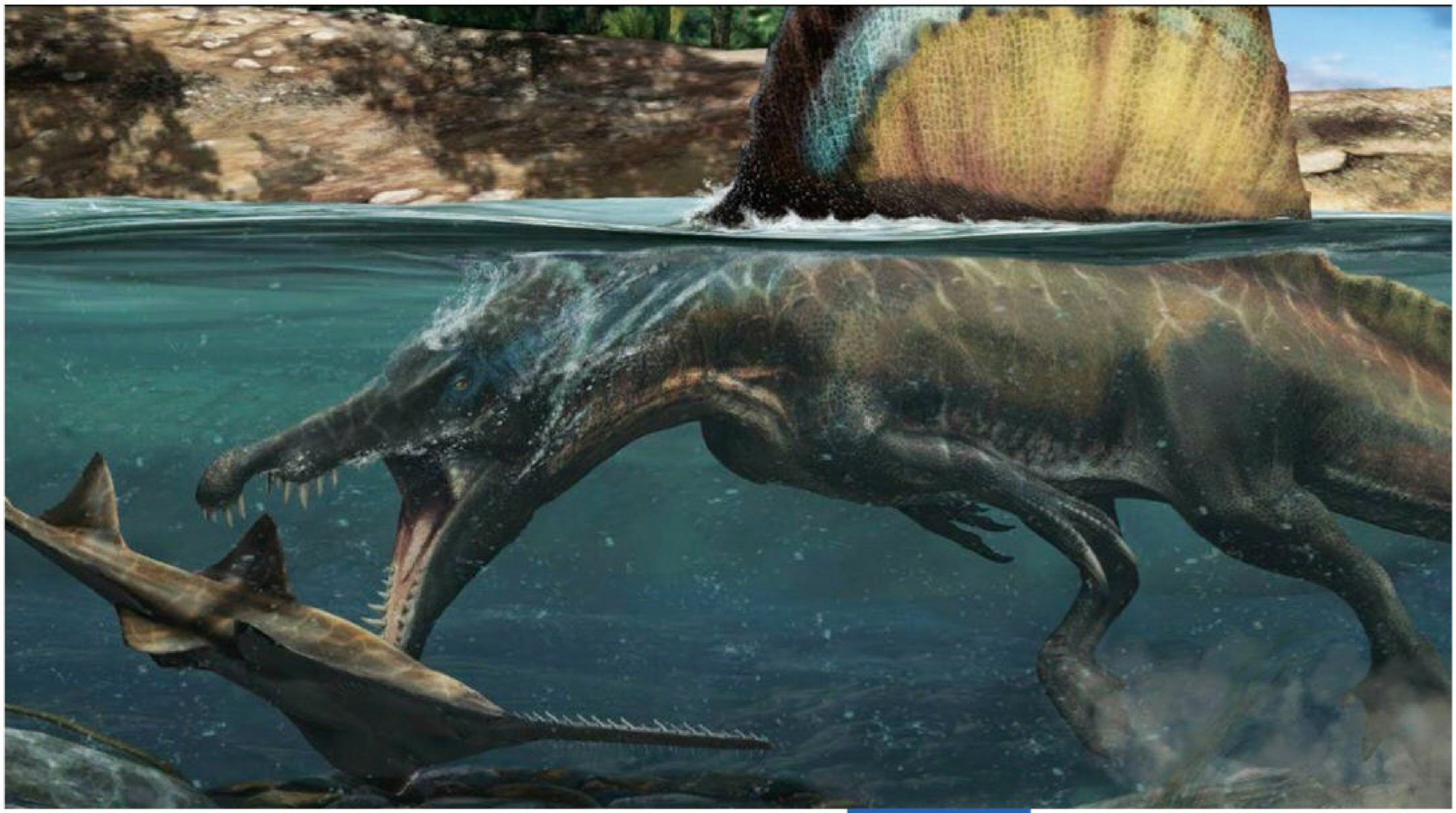
▲ Honour the humpback, elevate the antechinus or nominate the numbat. What's your favourite Australian mammal?

There are some familiar (often furry) faces among the candidates, but also opportunities to learn about lesser-known and underappreciated species – and let's not forget the marine mammals, like dugongs and many loved whales. Who knows, you might even find a new favourite mammal to call your own.

Visit **cosmosmagazine.com** to read about our charismatic compatriots and nominate your own favourite Australian mammal species – or email us at **contribute@cosmosmagazine.com** to tell us your pick.

And for bonus fun, check out the Australasian Mammal Taxonomy Consortium's Australian Mammals Species List as a great place to discover more species to celebrate.

FROM LEFT: JASON MCCAWLEY, TRACIE LOUISE, DEAN LEE/GETTY IMAGES.



▲ Spinosaurus: swimmer or wader? New research based on bone density suggests the former.

DAVIDE BONADONNA / SPINOSAURUS HUNTING

PALAEONTOLOGY

Did the biggest carnivorous dinosaur sink *and* swim?

Bone density analysis offers a likely answer to a hotly debated behaviour.

A team of palaeontologists led by Matteo Fabbri, a postdoctoral researcher at the Field Museum in Chicago, US, described in *Nature* how they took a new approach to puzzle out the behavioural ecology of the biggest carnivorous dinosaur that ever lived – the Spinosaurus.

Palaeontologists have long known that spinosaurids spent time by the water – their long, crocodile-like jaws and cone-shaped teeth are very similar to those of other aquatic predators, and some spinosaurid fossils have been found with bellies full of fish.

But it was widely believed that non-avian dinosaurs were the only group of terrestrial vertebrates that didn't have any water-dwellers – instead stopping in the shallows and dipping heads in to snap up prey, much like a heron on the foreshore.

In 2014, Nazir Ibrahim from the University of Portsmouth, UK, suggested that a new Spinosaurus specimen's retracted nostrils, short hind legs, paddle-like feet, and a fin-like tail pointed to an aquatic lifestyle. Many researchers held firmly to the belief that spinosaurids were waders, not swimmers.

Fabbri and his team decided it was time to find a new way to look at the evidence.

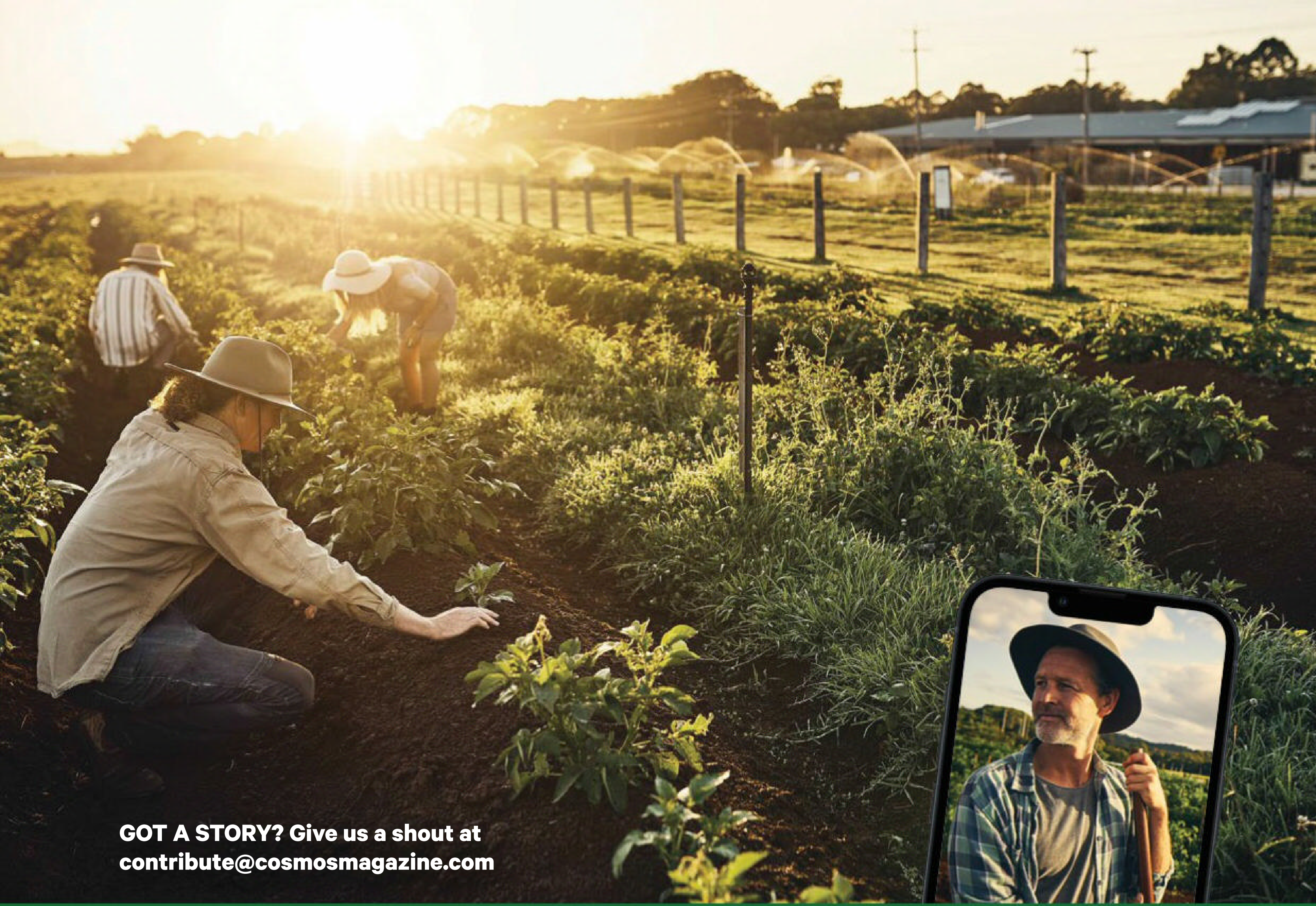
Bone density is a key determinant of whether an animal is able to sink beneath the surface and swim: dense bone works as buoyancy control and allows the animal to submerge itself.

The team compiled a dataset of femur and rib bone cross sections from 250 species.

"We were looking for extreme diversity," says Fabbri. "We included seals, whales, elephants, mice, hummingbirds. We have dinosaurs of different sizes, extinct marine reptiles like mosasaurs and plesiosaurs."

This menagerie revealed a clear link: animals that submerge themselves underwater to find food have bones that are almost completely solid throughout, whereas cross-sections of land-dwellers' bones look more like donuts, with hollow centres.

The team then took cross-sections of bone from Spinosaurus and its close relatives, Baryonyx and Suchomimus. Spinosaurus and Baryonyx both had the sort of dense bone associated with full submersion. The closely related Suchomimus had hollower bones, suggesting that while it still lived by water and ate fish, as evidenced by its crocodile-mimic snout and conical teeth, it wasn't actually swimming.



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We’re proud to have started publishing stories in our Greenlight Project: a year-long look at how regional Australia is dealing with climate change. People living and working outside Australia’s cities faces huge risks and equally huge opportunities through the challenges posed by moving to a low-emissions future. How will they fare?

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Please join us – there’s much to learn.
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Testing the *Dark Emu* hypothesis

The next big thing in Australian archaeology is hidden in plain sight.

VW PICS / GETTY IMAGES

One of the most interesting things going on in Australian archaeology is the idea that Aboriginal food production systems may have involved domestication of some plant species. Was there some level of food production going on in Aboriginal groups that goes well beyond hunter-gathering?

Plant geneticists haven't been working on these sorts of questions in Australia – and that's largely because we've assumed Aboriginal groups operated under hunter-gatherer systems.

I'm currently involved in research out in Mithaka country – the Channel country of southwest Queensland. Last year we published a large regional survey of the landscape, and we recently received a grant to continue that research, testing the hypothesis put forward by Bruce Pascoe in his book *Dark Emu*, bringing in plant geneticists, archaeobotanists, ethnobotanists, geomorphologists and palynologists (who study pollen cores to reconstruct environmental change). We aim to make a proper assessment of these landscapes and see if we can recover signatures of intensified plant use. We've called it "Testing the Dark Emu hypothesis".

Dark Emu is a very important book. Bruce Pascoe has connected people with an aspect of the Aboriginal past that most Australians have not previously engaged with at all. He's put forward a hypothesis, and we've identified a key landscape where we can test these ideas. This is an opportunity for archaeologists to work collaboratively with Aboriginal traditional owners to bring together teams incorporating a range of expertise that archaeology hasn't traditionally engaged with in this country.

We planned our first fieldwork for May – I spoke to Pascoe and he is thrilled that researchers are taking his research seriously.

PhD candidate Doug Williams has already identified the largest seed grinding quarry sites in the country – we've found thousands of these quarry sites with grinding stones for processing grain to make bread. The history records Aboriginal groups in the area were living in substantial villages – there's one account of a village of 103 huts. Whether these were permanent is unlikely – they were probably seasonal. But some of the dwellings were substantial structures, and we've started excavations.

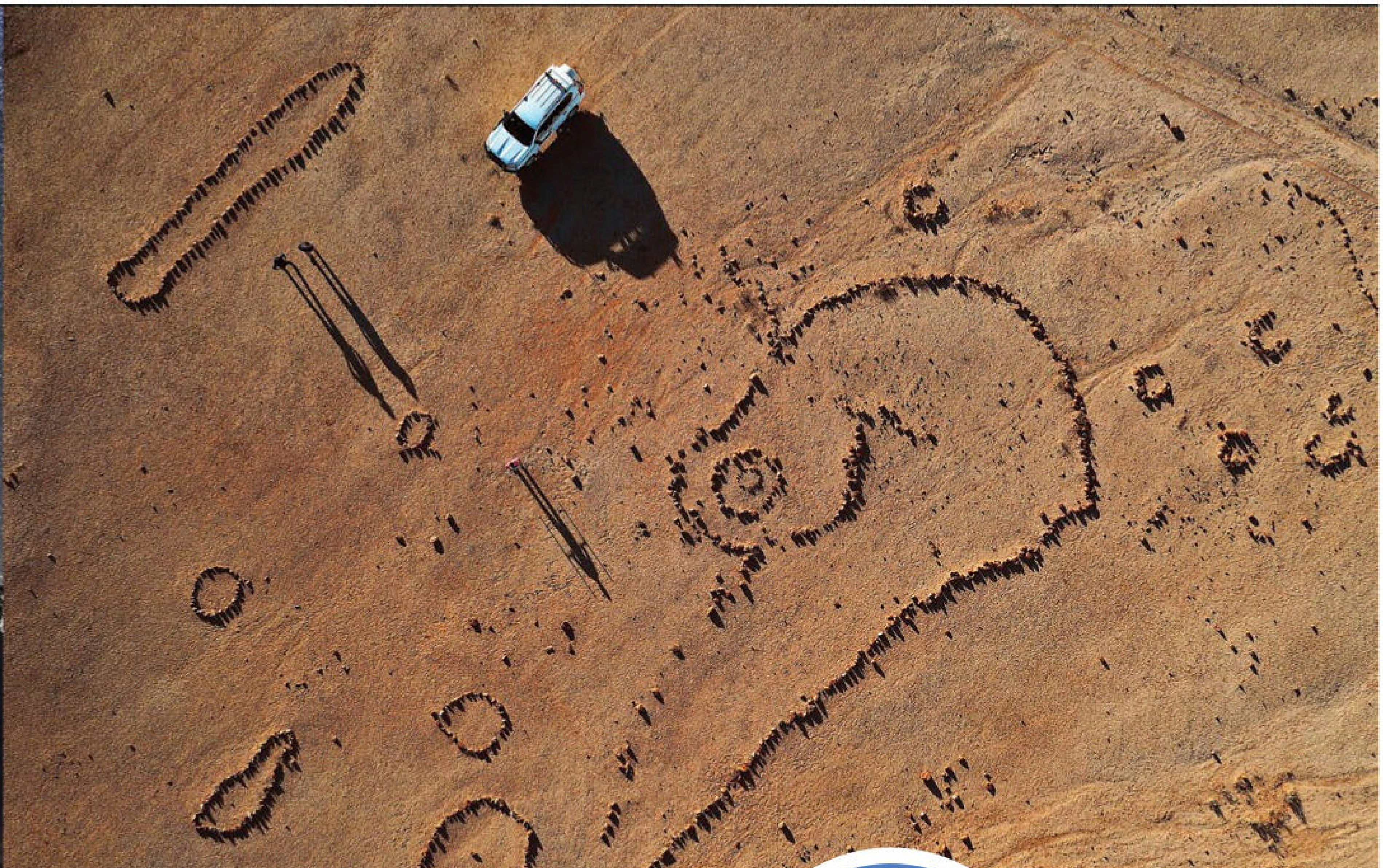
It's a new way of looking at archaeological landscapes in Australia, and thinking about these populations, not necessarily through the lens of hunter-gatherer society but as food producers.

We have revealed new evidence relating to a trading exchange network that extended from the Gulf of Carpentaria down to the Flinders Ranges in South Australia, with multiple goods moving up and down these desert channels – it's like Australia's version of the Silk Road.

This commerce wasn't necessarily built around gaining a material advantage, but more in developing partnerships across arid Australia, which sustained much larger populations in this region than we see today. There were likely thousands of Aboriginal people in that area. These are fascinating systems that we're only really beginning to understand through more widespread use of remote sensing technology (such as satellites and fixed-winged drones).

We've already found sites where villages were known to have existed, and we're now looking at magnetic anomalies to find more sites. Using a magnetometer, Dr Kelsey Lowe from UQ has found magnetic signatures that relate to Aboriginal use of fire. We're now applying this knowledge to landscapes we think could be the site of other villages.

One of the first roles of this project will be to excavate one of these potential village sites. Archaeobotany isn't a discipline that's been applied a great deal in Australia, but it's important work. For most archaeologists,



Michael Westaway (above) is part of a multi-disciplinary archaeological team assessing plant use and settlements in Mithaka country in conjunction with traditional owners.

FROM TOP: LYNDON MECHIELSEN, UNIVERSITY OF QUEENSLAND

the smallest sieve mesh they use is two millimetres. But most Australian seeds are less than 1mm. We were never going to recover archaeobotanical remains using traditional methods, but archaeobotanists Professor Andy Fairbairn and Dr Nathan Wright are recovering large quantities of seeds with these excavations using a finer mesh.

We don't know if these food production practices are widespread. I think there's a lot of regional diversity in Aboriginal social and economic systems. When we use the label hunter-gatherer, people think it's the same economic system everywhere, but I think there's a huge amount of variation in the nature of Aboriginal food production systems around the country. Some may be reliant on aquatic resources one season – the next season, there may be a fairly intensified foraging strategy. Others, such as Aboriginal groups in Cape York and the Torres Strait Islands may have been cultivating plants in lean seasons, then in better seasons, they're able to harvest marine resources. There's an exciting degree of variation and flexibility that we need to untangle.

The Channel country in southwest Queensland is the last unregulated desert channel system in the world. I was taken aback that the state government has given exploratory licences for fracking in that landscape. Our research has supported a nomination for National Heritage listing on some of the massive sites, that have now been shortlisted.

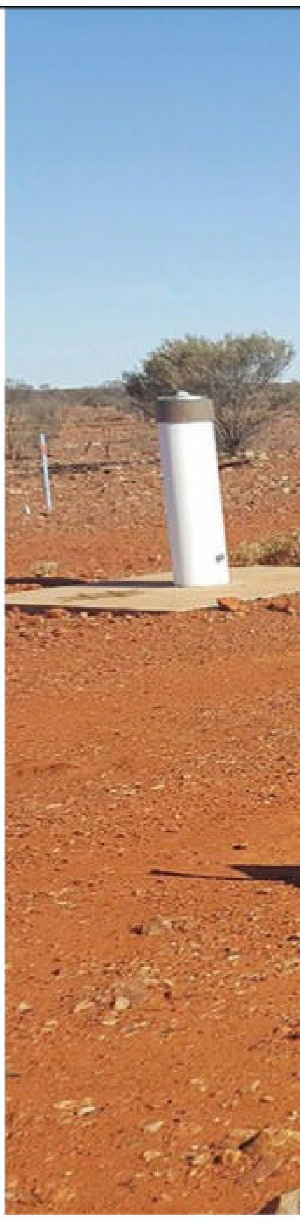
So we've got this strange situation with the state government looking at exploitation for fracking while the federal government is considering this landscape for National Heritage listing.

The archaeological record of this vast region is largely intact. It would be a national tragedy if fracking was able to get into the landscape, so well preserved, and before we actually know its significance. These are internationally significant heritage values when you consider the scale of these sites. They're monumental in terms of Australian archaeology, and we've barely scratched the surface.

Cultural heritage records shouldn't be seen as an obstacle to progress – it actually should be seen as a resource to foster things like cultural tourism and education and regional growth. People travel from all over the world to go to the south of France to see their amazing archaeological landscapes – the French are so proud of their "préhistoire".

But it's a big challenge getting Australians interested in the importance of the archaeological record of the First Australians. It's a sad reflection on how we value Aboriginal heritage. There's a lot of challenges, but equally a landscape like that in Mithaka country – and importantly, the enthusiasm that the Mithaka people have for conserving and sharing their heritage – offers great hope. ⊛

MICHAEL WESTAWAY is an Associate Professor of archaeology at the University of Queensland and an Australian Research Council Future Fellow.



School of rocks

How are we here? Why is the Earth the way it is? The way life arose in our solar system remains a fascinating mystery. Beset but not daunted by kangaroo scat, this astrogeologist is piecing together the origins of life on Earth, meteorite by meteorite.

An educational resource for this story is available at **www.education.australiascience.tv**

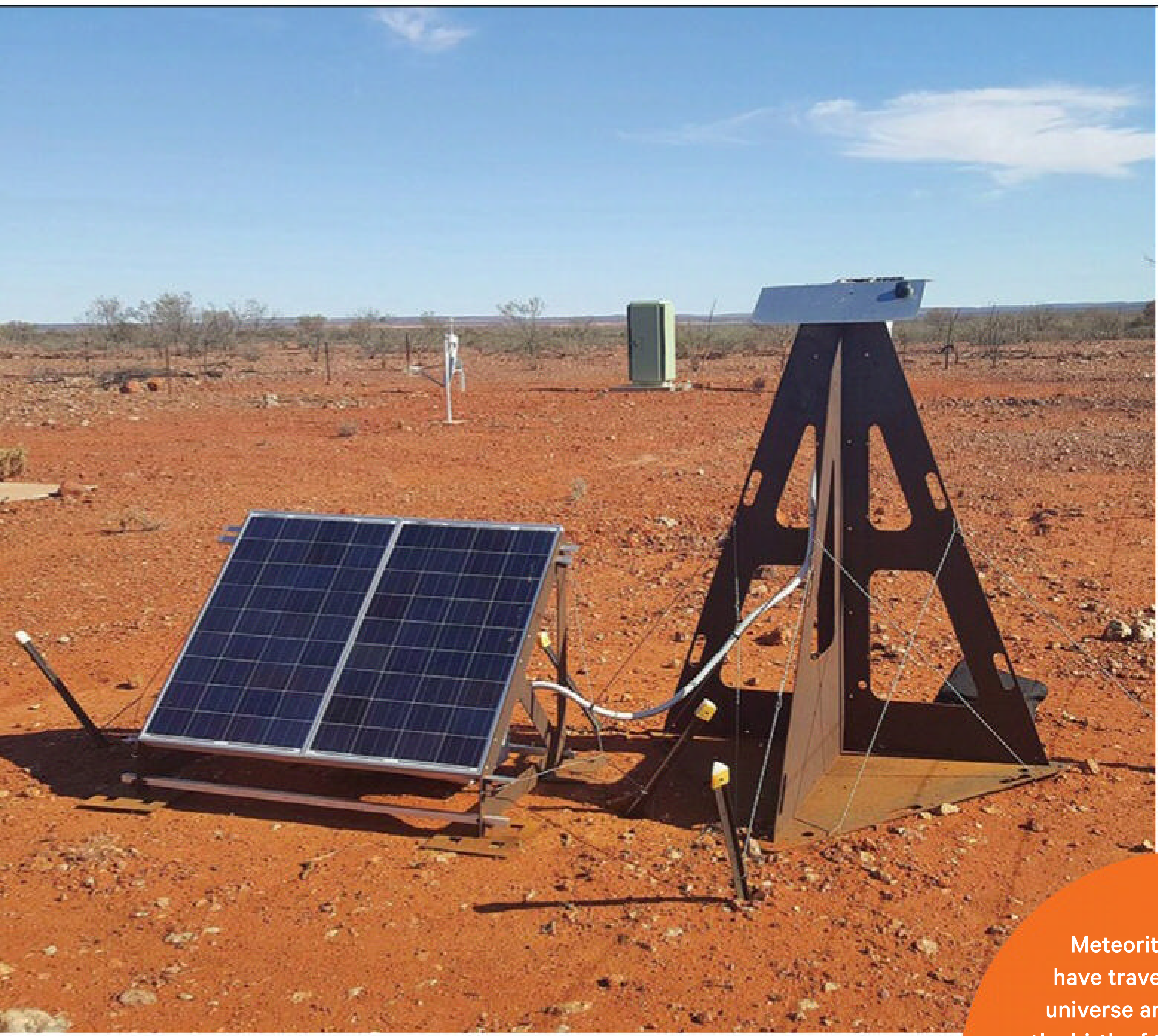
I was part of NASA's Astrobiology Institute when it was first formed back in the late 1990s – we were trying to figure out how life forms out in space.

We had biologists, astronomers and geologists all coming together to talk to each other. But we didn't know each other's languages. It's been really interesting over the last 20 years to see how we've grown together. We still aren't totally fluent in each other's languages – but it makes such a difference when you get to that interdisciplinary place. This kind of collaboration is so important.

My specialty is astrogeology, but I came to it in a roundabout way. I actually started university as a psychology major, but one of my electives was an astronomy unit, and I liked it so much I jumped over to a physics degree.

It was a big change of mindset, but I found it so interesting to think about where we fit in the universe and in the solar system. Along the way I got very interested in particle physics. Then during my Master's I was thinking a lot about the surfaces of asteroids, so I took a couple of geology units to help wrap my head around it, and that was when I went, "Yeah, that's the thing I've got to do. What a great place to be. Rocks in space." And so I did a PhD in geology.

TOP: RMHOWIE / WIKIMEDIA X2. GRETCHEN BENEDIX



Meteorites (opposite) have travelled across the universe and offer clues to the birth of the Solar System, but how to find this special rock amongst the jumble? The Desert Fireball network (above) tracks them to Earth, giving researchers a treasure map to follow.

Part of the reason I'm based in Australia now is a project called the Desert Fireball Network. It's a bunch of cameras spread out across the Nullarbor Plain that take pictures every night, because there's material hitting the Earth from space and it's easiest to see it at night.

These images are very long exposures, and you can get a lot of information from fireballs by the trail they leave. Then the group is able to track the fireball to work out where on the ground the meteorite might land. That's where I come in. I can look at the rock and tell you a lot about its parent.

When the meteorites come through the atmosphere, they get kind of melted and this forms something like a glassy rind. So you get a very smooth surface. The biggest one we've retrieved was about the size of a rockmelon, but they're not spherical. This is because they tumble as they fall through the atmosphere, and melt preferentially. And because they're from space they've been kind of beaten up as well. So they're like little jumbled pieces of rock.

A great thing about the Nullarbor is that it's a big carbonate plain, and carbonate is a very light-coloured rock. And meteorites are generally quite dark coloured – the glass that forms isn't clear, and the melted elements of the meteorite usually come out very dark, almost black.

When hunting for meteorites in Australia, we have an interesting issue to deal with. Meteorites can be quite small and round and dark by the time they hit the ground. Another thing that exists on the Nullarbor Plain that is also small and round and dark is kangaroo poop. We poke anything promising with a stick before picking it up.

Meteorites give us a lot of information about the origin and early history of the solar system. A lot of the rocks we find haven't experienced a whole lot of geologic processing since they formed. So when we date them we can find out the last time anything significant occurred. And most of the rocks that we get are in the vicinity of four and a half billion years old, which is how we define the beginning of the solar system.

Some of these rocks give us the original elemental composition of the cloud of dust and gas that collapsed to become the solar system. What is really important is we can compare other things to that original composition, so you can say something about the geologic processing that has occurred over time. The more rocks we find, the more we can have a really good working theory of how the solar system formed.

That's the thing with meteorites. We can have these really primitive ones. And then we have other ones that have experienced some kind of evolution, similar to Earth, where it's been kind of converted – perhaps the whole thing melted and then you get separation of densities of materials. We can learn a lot about how planet formation works from those things.

Why is the Earth the way it is? If we look at the history of the Earth, we can see there's always been quite a bit of water, and water is the most efficient catalyst in life, forming chemical reactions. So if you have water present, and you have the organic materials present, all you need is an energy source and you're likely to kick things off.

There's obviously organic material here on Earth – and we know there's organic material in meteorites. It just hasn't gone the full way into turning into life – not even single-celled organisms exist, as far as we can tell. So we're trying to figure out why Earth is the way it is, and what that really means. Why are we here? What is it about this place that makes it that we're able to survive here, and all the things that have evolved from a single-celled organism up to where we are now?

How does this all fit together? How does life start? Does it have to happen at a certain time, or can it occur at a range of times and still kick life off? Does it have to start on a planet of a very specific size, with a very specific atmospheric composition, a very specific amount of water? Or is there a bit of randomisation?

We're working towards finding those answers, rock by rock. ◉

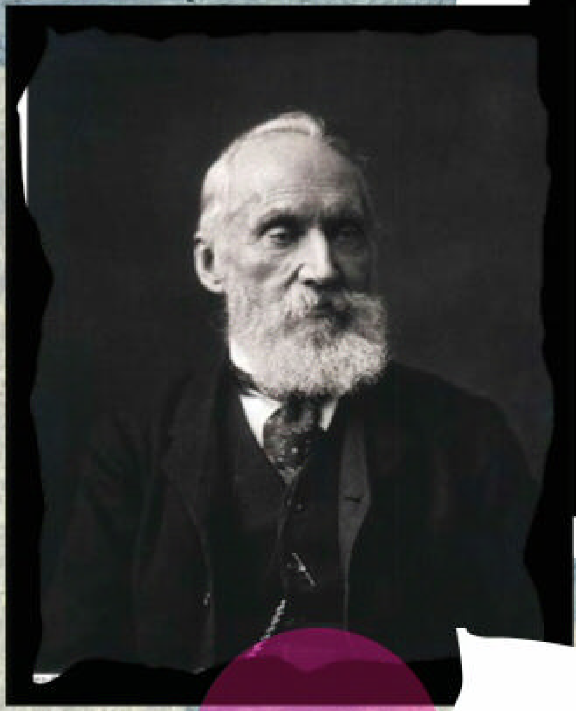
GRETCHEN BENEDIX is a professor in the School of Earth and Planetary Sciences at Curtin University, Perth. She is a cosmic mineralogist and astrogeologist using the chemistry, mineralogy, spectroscopy and petrology of meteorites to understand the formation and evolution of asteroids and other planets.

HEAVYWEIGHT PARTICLE

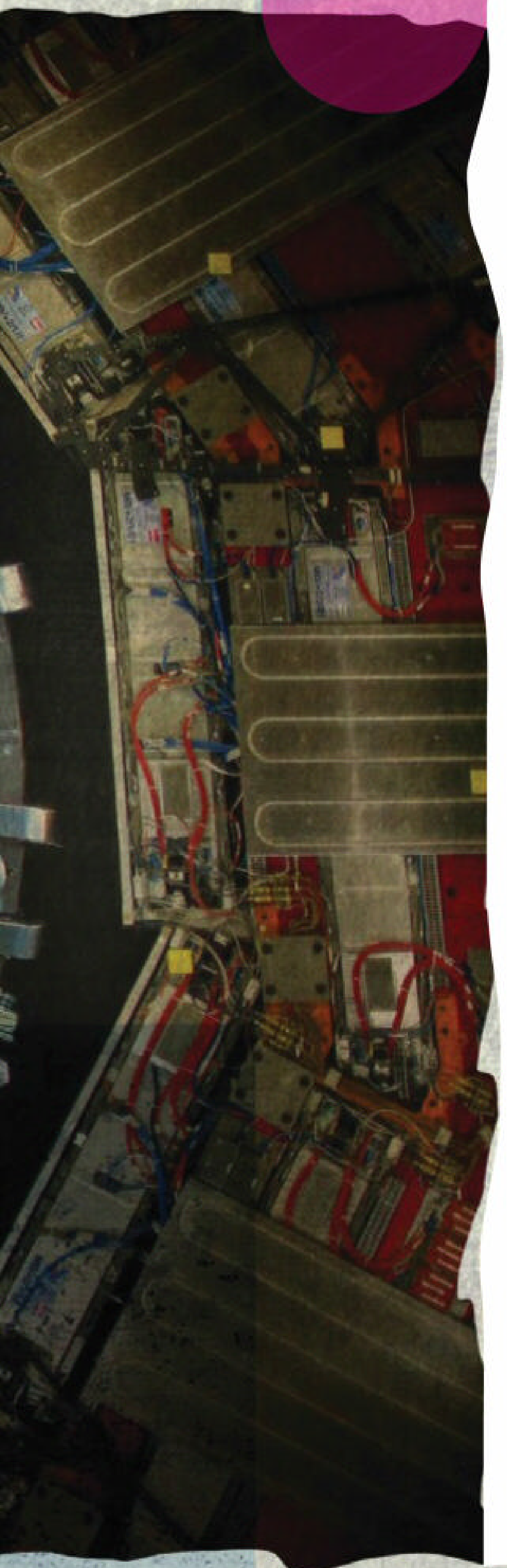
The Large Hadron Collider (LHC) at CERN, in France and Switzerland, entered legend as the place where the Higgs Boson was discovered in 2012 – a feat celebrated with life-sized backlit photographs (right) and other installations at a Science Museum exhibition in London a year later. The latest discovery to rock physics' world comes not from the LHC, but Tevatron, in the US – a particle collider that hasn't run for more than a decade.

BACKGROUND: OXYGEN/GETTY IMAGES. LORD KEVIN: SMITHSONIAN INSTITUTE

The announcement in April of new measurements of the W boson has particle physicists abuzz. **MARTIN WHITE** gets the knowledge collider up to peak energy to examine what we know and what the new W measurements might mean.



Lord Kelvin



In the late 19th century, the British mathematical physicist and engineer Lord Kelvin, whose bearded visage once adorned the £100 banknote, is reported to have made a remarkable statement about physics. His famous quote – "there is nothing new to be discovered now, all that remains is more and more precise measurement" – is a concise statement of what is thought to be a prevailing attitude at that time: the sense that physics was almost finished.

After all, a student at that time could learn most of our current high school curriculum, including the laws of mechanics, thermodynamics, electromagnetism and optics. Furthermore, the application of these principles to the development of the telephone, internal-combustion engine, electric light and radio would have been almost inconceivably mind-blowing and fantastic, breeding a confidence that seemed set to last forever.

The problem with this account – as is often the case – is that Lord Kelvin never said it.

Although it would take over 100 years for the term "fake news" to enter the popular lexicon, the ghost of Kelvin has every right to complain about slander. He was close enough to thermodynamics to know that major surprises lay around the corner; indeed the next 30 years of physics played like a greatest hits of human intellectual achievement.

Einstein's famous theory of special relativity arrived in 1905, followed by the discovery of the nucleus in 1911, Einstein's general relativity in 1916, the discovery of galaxies in 1923 and Schrödinger's famous equation of quantum mechanics in 1926. As the 20th century progressed, a "Standard Model" of particle physics emerged which describes the fundamental constituents of the universe and how they interact, allowing us to understand the microscopic world with staggering precision.

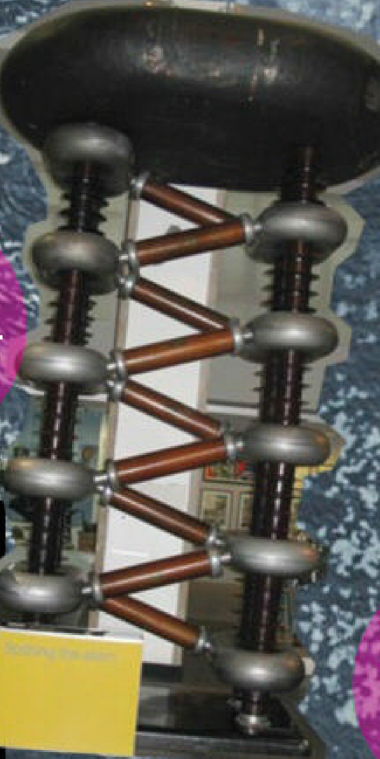
Flash forward to the present day, and the scientific parallels with the 19th century are as striking as the fashion for ridiculous Victorian facial hair. One often hears the view that "there is nothing new to be discovered in particle physics now, only more and more precise measurements". The largest particle accelerator ever built – CERN's Large Hadron Collider, in France and Switzerland – has been running for over a decade, with about 10,000 physicists employed to sift the results of proton collisions for evidence of new particles.

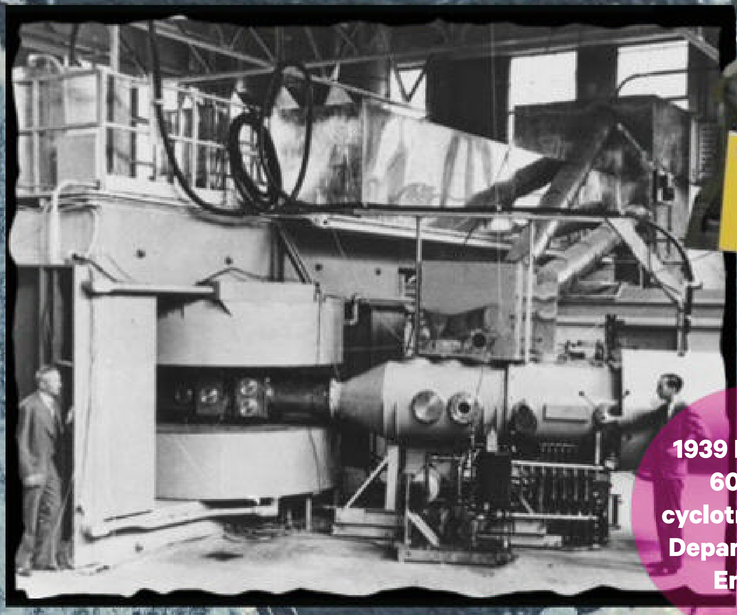
Despite a gargantuan effort, we have thus far uncovered nothing that definitely rejects the Standard Model as the correct description of nature, although a series of intriguing anomalies exist in the measurements of particles known as "B mesons", and in measurements of an electron-like particle known as the "muon" (see "Is the Standard Model broken?", in Cosmos 91).

Nevertheless, reports of the death of particle physics are as fictional as Kelvin's mythical myopia. In a striking development, a team from an earlier collider – the Tevatron at Fermilab, in Illinois, US – has recently burst onto the scene like an old flame in a soap opera, claiming that one of the hitherto best understood particles in nature is not what we thought it was.

By measuring the mass of the W boson with outrageous precision, they have obtained a result that is not only inconsistent with previous measurements, but is inconsistent with the Standard Model itself based on our knowledge of other particle properties. The result is a

1930s

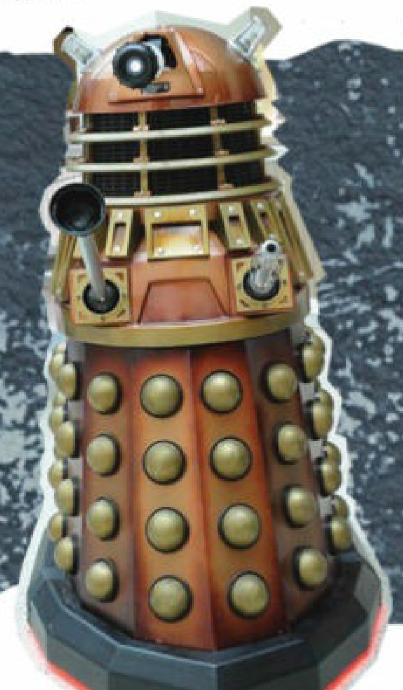

1932 Cockcroft-Walton generator


1939 Berkeley 60-inch cyclotron by US Department of Energy

$$
\begin{aligned}
\mathcal{L} = & -\frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{8}tr(\mathbf{W}_{\mu\nu}\mathbf{W}^{\mu\nu}) - \frac{1}{2}tr(\mathbf{G}_{\mu\nu}\mathbf{G}^{\mu\nu}) \\
& +(\bar{\nu}_L, \bar{e}_L)\,\tilde{\sigma}^{\mu} iD_{\mu}\begin{pmatrix}\nu_L \\ e_L\end{pmatrix} + \bar{e}_R\sigma^{\mu} iD_{\mu}e_R + \bar{\nu}_R\sigma^{\mu} iD_{\mu}\nu_R + (\text{h.c.}) \\
& -\frac{\sqrt{2}}{v}\left[(\bar{\nu}_L, \bar{e}_L)\,\phi M^{e} e_R + \bar{e}_R \bar{M}^{e} \bar{\phi}\begin{pmatrix}\nu_L \\ e_L\end{pmatrix}\right] \\
& -\frac{\sqrt{2}}{v}\left[(-\bar{e}_L, \bar{\nu}_L)\,\phi^{*} M^{\nu} \nu_R + \bar{\nu}_R \bar{M}^{\nu} \phi^{T}\begin{pmatrix}-e_L \\ \nu_L\end{pmatrix}\right] \\
& +(\bar{u}_L, \bar{d}_L)\,\tilde{\sigma}^{\mu} iD_{\mu}\begin{pmatrix}u_L \\ d_L\end{pmatrix} + \bar{u}_R\sigma^{\mu} iD_{\mu}u_R + \bar{d}_R\sigma^{\mu} iD_{\mu}d_R + (\text{h.c.}) \\
& -\frac{\sqrt{2}}{v}\left[(\bar{u}_L, \bar{d}_L)\,\phi M^{d} d_R + \bar{d}_R \bar{M}^{d} \bar{\phi}\begin{pmatrix}u_L \\ d_L\end{pmatrix}\right] \\
& -\frac{\sqrt{2}}{v}\left[(-\bar{d}_L, \bar{u}_L)\,\phi^{*} M^{u} u_R + \bar{u}_R \bar{M}^{u} \phi^{T}\begin{pmatrix}-d_L \\ u_L\end{pmatrix}\right] \\
& +\overline{(D_{\mu}\phi)}D^{\mu}\phi - m_h^2[\bar{\phi}\phi - v^2/2]^2/2v^2.
\end{aligned}
$$

Standard Model shown as an equation

1960s



tantalising mystery that may be our clearest view yet that a new theory will one day supersede the Standard Model.

To understand why, we need to first explore the Standard Model itself, and the bizarre world of quantum field theory.

Building a LEGO universe

Imagine for a moment that you win the lottery, and you decide to buy your child the biggest LEGO set in the world to celebrate. The biggest LEGO set in the world turns out to be the world itself! In LEGO, one can build anything by choosing and putting together different combinations of fundamental blocks.

Somewhat magically, the universe acts on similar principles, except that the blocks are much, much smaller. We're mostly made of particles called up and down quarks – which make up most of the nuclei of our atoms – and electrons, which orbit the nuclei. We've also discovered neutral particles called neutrinos, that are emitted when atoms decay via radioactivity, and there is an "electron neutrino" that shares some properties with the electron but which does not interact with the electromagnetic force.

For a reason no-one understands, however, there are heavier versions of each of these quarks and electron-type particles, which are given exotic names like the "charm", "strange", "bottom" and "top" quarks, and the "muon" and "tau" leptons.

The complete set of matter particles in the Standard Model of particle physics is shown opposite. These particles are the basic building blocks from which atoms themselves are built. The blue boxes, meanwhile, contain particles which are associated with the forces of the Standard Model, through which particles interact.

Although in LEGO there's only one way of joining bricks together (you just shove them into each other), in the universe there are four forces that we know of. Three of these – the strong force, the weak force and electromagnetism – are seen in the boxes through their associated particles (gluon, W and Z bosons and photon respectively), and gravity is famously absent until the requisite genius determines how we can fit it in.

Finally, it turns out that there is no way to give particles any intrinsic mass in the Standard Model, and we have to instead add a particle whose interactions give rise to that mass. This final ingredient is called the "Higgs boson" after Professor Peter Higgs, who proposed it around the same time that the first episode of *Doctor Who* aired, only to have to watch almost 50 years of Dalek invasions before the boson was discovered.

The real Standard Model

The Standard Model is far more than just a list of things we have seen. The real Standard Model is shown in the equation above, written in the hieroglyphic language of "quantum field theory".

Whilst it may look completely impenetrable, the beauty of this equation is how much of it makes sense

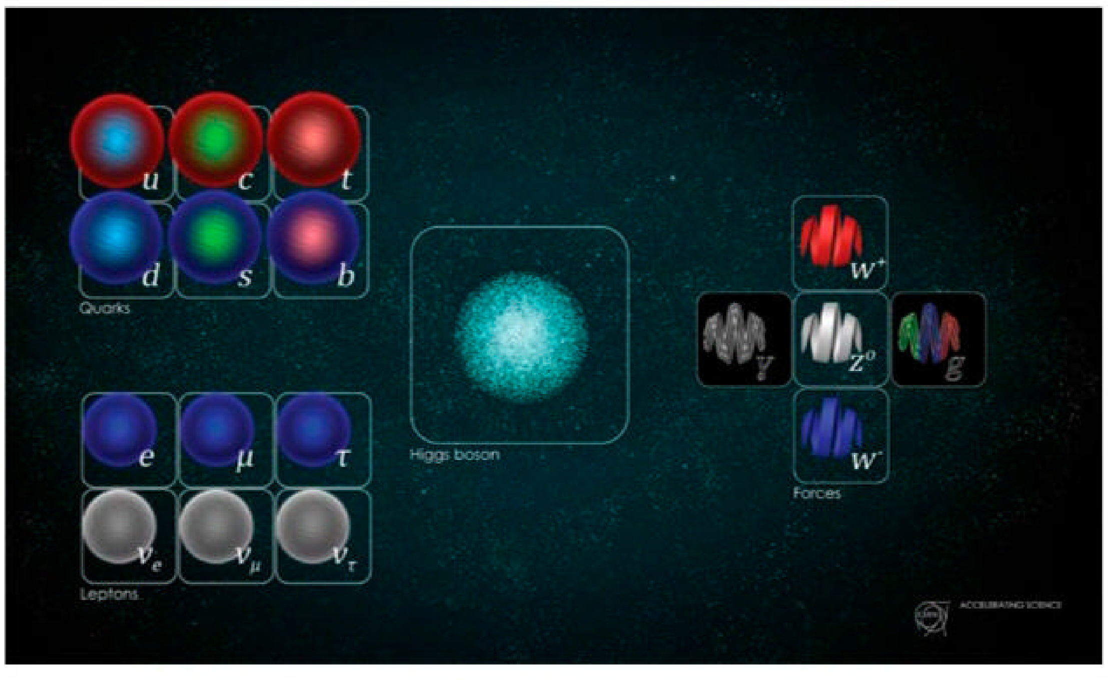
The Cockcroft-Walton generator, or multiplier (above centre), powered the particle accelerator that in 1932 achieved history's first artificial nuclear disintegration. Ernest Lawrence's 60-inch cyclotron (top left) was one of several ever-larger circular particle accelerators he built. The Standard Model's particles (opposite): quarks and leptons are matter particles, which constitute part of the "stuff" that the universe is made of. The forces (bosons) bind particles together. The last piece of this puzzle, the Higgs boson, is required to explain why particles have mass. The elusive Higgs' discovery crowned a 50-year hunt – roughly the period graced by *Doctor Who's* Daleks (above) – that earned a Nobel Prize for Peter Higgs and François Englert in 2013.

FROM LEFT: US DEPARTMENT OF ENERGY, GENI / WIKIMEDIA, ALBERT L ORTEGA/GETTY IMAGES

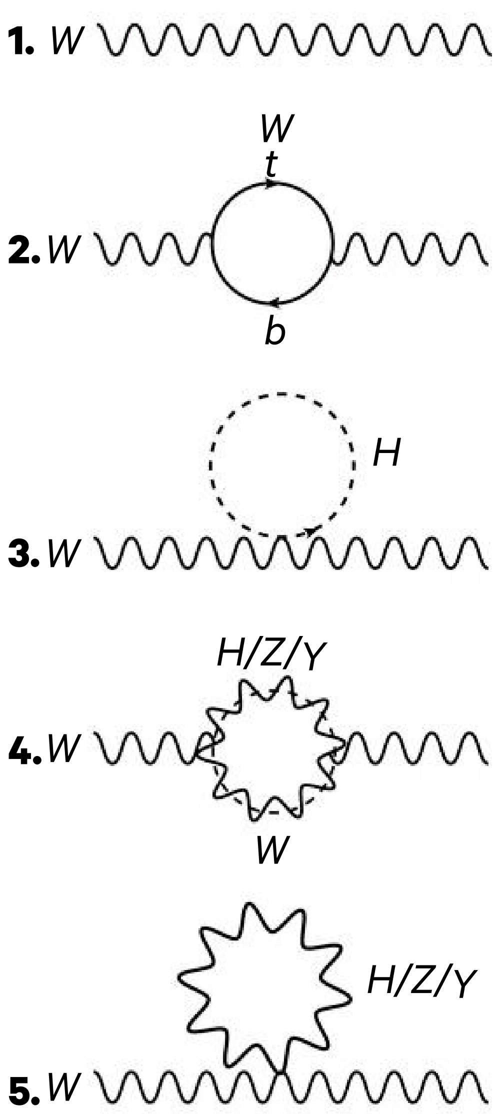
no matter what level of education someone has. Most primary school children could recognise the fractions, equals sign, plus and minus signs, whilst most high school children will recognise algebra, square numbers, and things that look a bit like vectors. In fact, the equation contains every particle that we see in the box below, except that the most convenient way to represent them is as "quantum fields" which fill all of space. Imagine that you look inside a mattress, and see a network of springs. By banging the springs, you could make waves that propagate over the mattress, and by banging it lots of times you could make different waves that interact with each other, join together, and split apart. The basic idea of quantum field theory is very similar, except that the springs become "fields" that fill all of space, and banging the springs is called "exciting the fields" to make particles.

Quantum mechanics, with its simultaneously dead and alive cats, is famously bizarre, and indeed the "quantum" in quantum field theory should be a clue that the Standard Model is very strange in practice. What this means for our simple particle picture is that our LEGO block analogy is far too simplistic.

Any parent of LEGO-obsessed children will know that LEGO blocks can disappear and reappear randomly, but at least we can say that each LEGO block stays the same when it's in hiding. The building blocks of nature, however, follow bizarre rules in which pretty much anything can happen. A W boson winding its merry way through the universe can randomly turn into other particles before continuing (*see right*), a phenomenon known as a "loop effect" by physicists. The rules of the Standard Model allow us to calculate how these strange encounters would affect the results of the particle physics experiments that we do and, in this case, the effect is to shift the measured mass of the W boson. In other words, the value of the W boson mass that we should expect to observe in our various colliders changes relative to what would happen if loop effects did not exist.



CERN

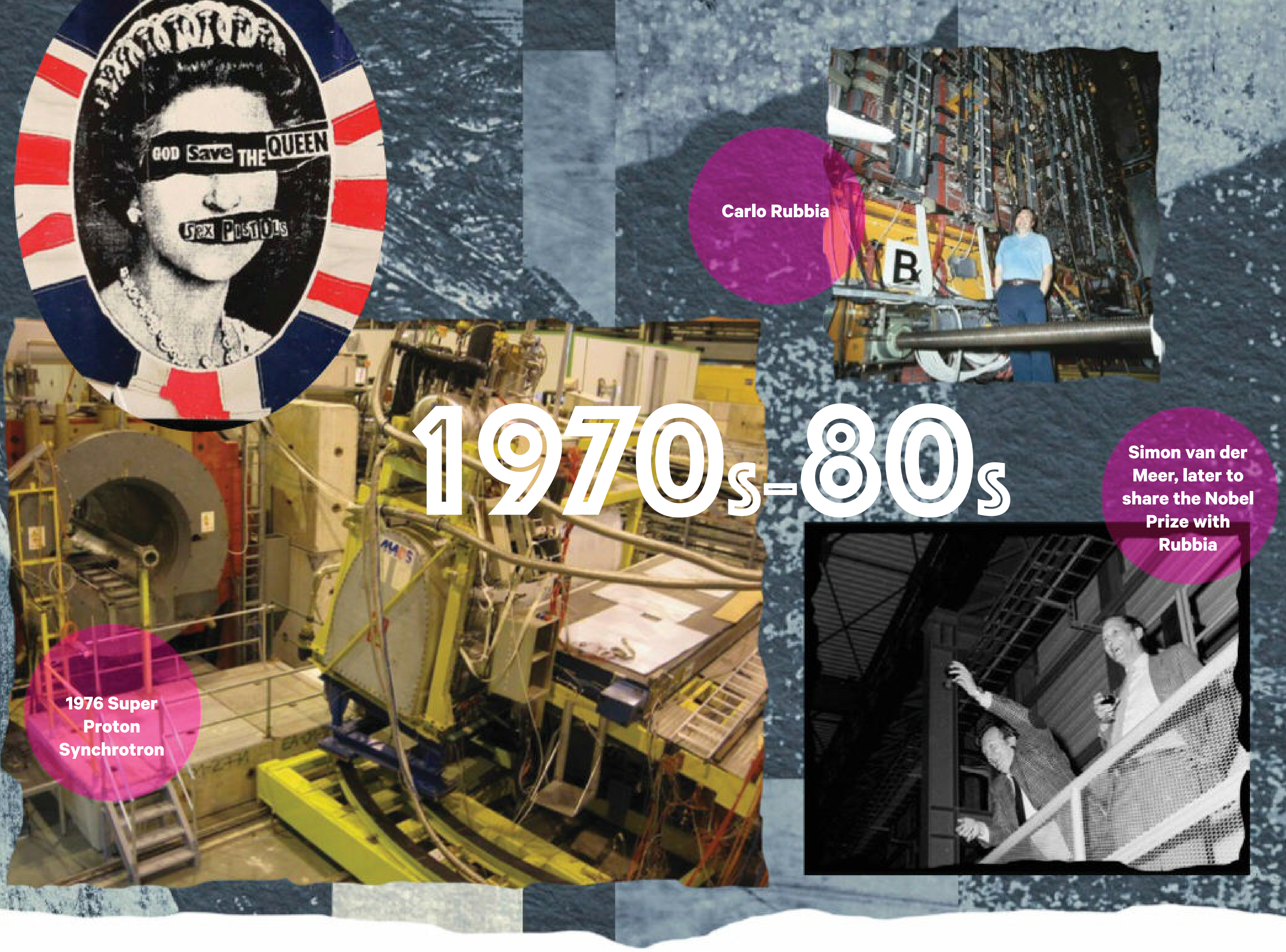


A PHYSICIST DOODLES A W BOSON TAKING A WALK

The simplest way this can happen is for the W boson to move from here to there, which we conventionally draw with a wiggly line **(1.)** following rules proposed by Richard Feynman. Quantum funkiness, however, means that the W boson could just as easily split into a pair of quarks **(2.)** which then recombine to form a W boson. Or it could split into other particles, or randomly launch other particles in the strange variety of combinations in the remaining diagrams. These effects are known as "loop effects" because the doodles that describe them contain loops of particles.

This notion of loop effects turns out to be absolutely critical to modern particle physics. Across the Standard Model as a whole, loop effects are relevant for each and every matter particle and force particle. By measuring particle properties very precisely, and comparing them to our total set of calculations, we can determine if the Standard Model predictions match the data. For example, since the discovery of the Higgs boson in 2012, thousands of physicists have been engaged in measuring its mass very precisely, and measuring how often it decays to the various other particles of the Standard Model. The Standard Model allows us to calculate how often each of these decay processes occur if we know the mass, and hence the set of measurements allows us to check if the Standard Model correctly describes the Higgs boson. The answer so far is that it does, at least within the precision of our current measurements. If the predictions we make about all Standard Model particles do match the data, we can be sure that the Standard Model provides a good description of nature. If they don't, there are only three options: (1) the Standard Model is true but we made a mistake in the calculations; (2) the Standard Model is true but we messed up the measurements; or (3) the Standard Model can't be true.

1970s–80s



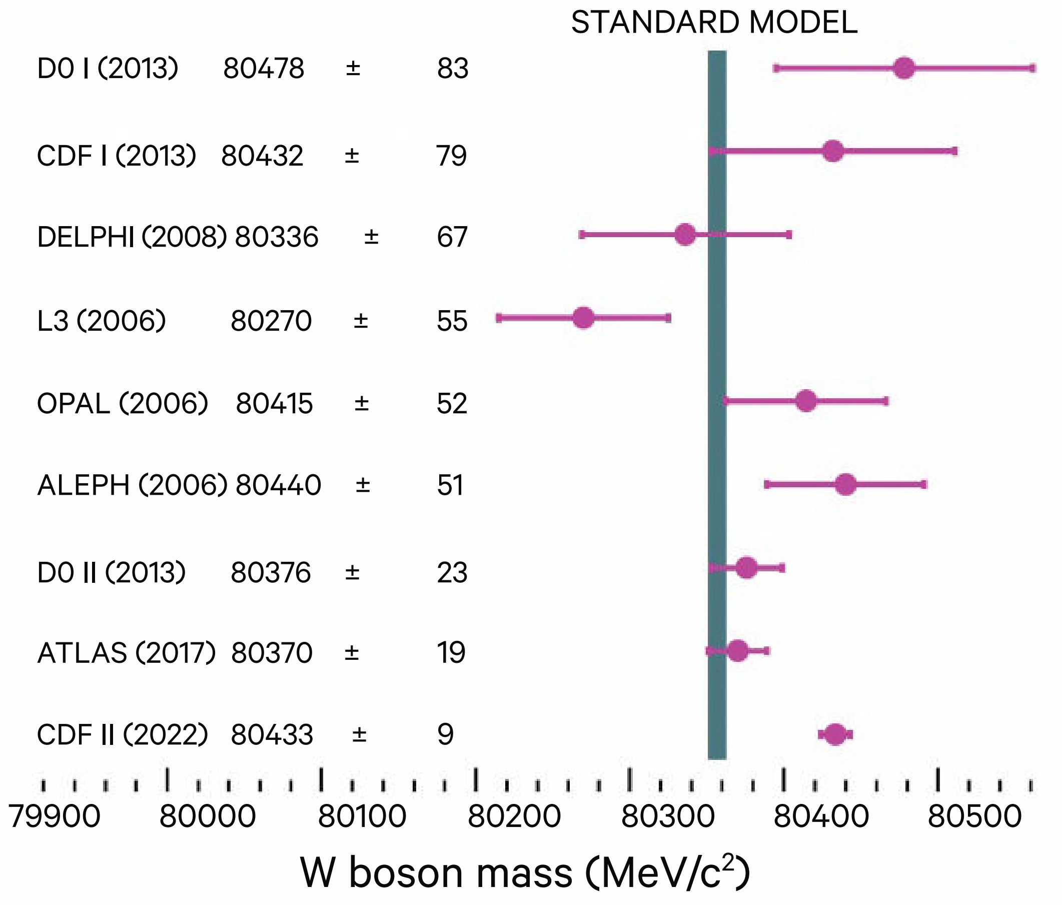
Carlo Rubbia

Simon van der Meer, later to share the Nobel Prize with Rubbia

1976 Super Proton Synchrotron

MADE TO MEASURE

With each result the uncertainty (horizontal line) has reduced, but the measurement (dot) has varied both above and below the expected Standard Model value. The CDF measurement has the smallest uncertainty band, and is higher than or similar to the more recent measurements. It's also notably higher than the Standard Model's expectation, to a level that appears inconsistent with it surviving as a valid theory.



The excitement of option 3 is that we know exactly how the Standard Model would have to be changed to accommodate discrepant measurements. New particles beyond those shown in the Model would have to exist, and they would have to add more possibilities (and therefore extra diagrams) to the set. This, in turn, would lead to a new calculation that matches the data precisely. For this reason, a huge proportion of the world's best particle physicists are constantly busy working out how to make more precise measurements or more precise calculations of particle properties.

How we learned to stop worrying and love the Standard Model

The theoretical construction of the Standard Model was mostly complete by the mid 1970s, just in time for punk. Our first sighting of the W boson, however, did not occur until 1983, when the top-selling album in Australia was Michael Jackson's aptly named *Thriller*. What happened in the interim is so dramatic that it was once sensationalised by Playboy journalist Michael Taubes in the book *Nobel Dreams: Power, Deceit, and the Ultimate Experiment*.

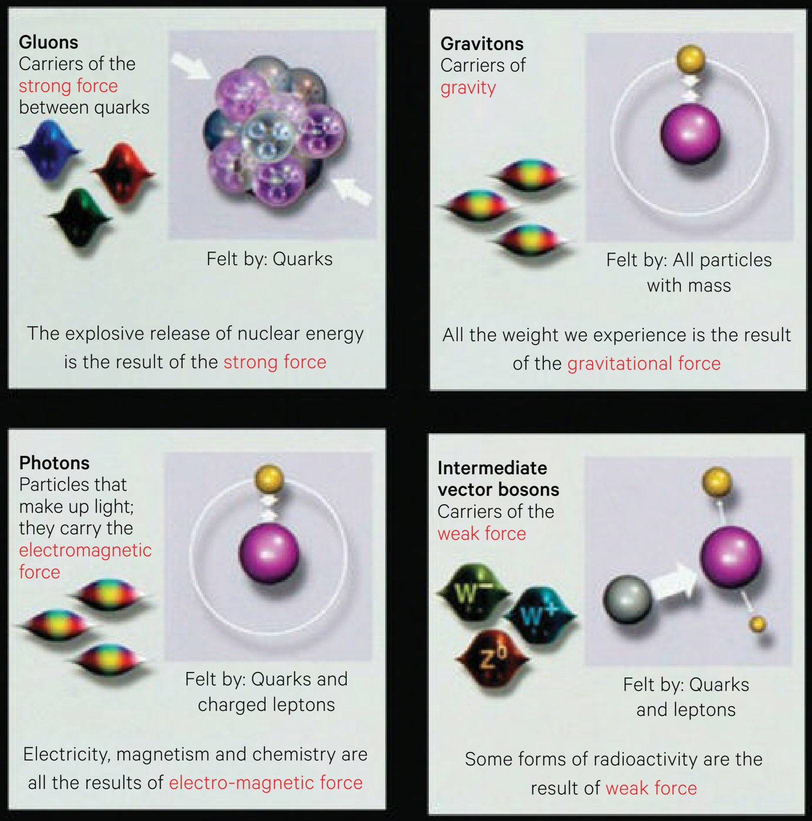
The classic way to discover a particle is to smash particles together at high energy in a particle accelerator. This creates a dense region of super high energy that can form new particles through quantum weirdness; giant detectors surrounding the collision point analyse the particles produced. To shield the apparatus from particles that reach Earth from space, the whole thing has to be done 100 metres underground, and accelerating the particles requires huge circular tunnels.

FROM LEFT: AFP/GETTY IMAGES. GILLIS/WIKIMEDIA. CERN X2

1980s–2000

Commissioned in 1976 – early in the Sex Pistols era – the Super Proton Synchrotron (SPS; opposite top left) is housed in a circular 6.9km tunnel at CERN. In the 1980s the SPS's maestros, Carlo Rubbia and Simon van der Meer steered it to the discovery of the W and Z bosons, for which they won a Nobel Prize in 1984. During the years that Michael Jackson ruled the airwaves, the 27km-circumference Large Electron-Positron (LEP) collider at CERN, commissioned in 1989, was used to learn more about W and Z bosons. The LEP was closed to make way for the LHC in 2000. The LEP's accelerating cavity (above, left) is today on display at the National Museum of Scotland, in Edinburgh – and requires regular dusting.

Force particles
These particles transmit the four fundamental forces of nature although gravitons have so far not been discovered



Gluons
Carriers of the strong force between quarks
Felt by: Quarks
The explosive release of nuclear energy is the result of the strong force

Gravitons
Carriers of gravity
Felt by: All particles with mass
All the weight we experience is the result of the gravitational force

Photons
Particles that make up light; they carry the electromagnetic force
Felt by: Quarks and charged leptons
Electricity, magnetism and chemistry are all the results of electro-magnetic force

Intermediate vector bosons
Carriers of the weak force
Felt by: Quarks and leptons
Some forms of radioactivity are the result of weak force

Colliders can be distinguished by the types of particles they smack together, the energy with which they do so, and the luminosity (which is a measure of how often the particles collide). Already in the early '70s, it was possible to calculate roughly how heavy the W boson should be, based on everything else known at that time. Unfortunately, the answer was that the W was way heavier than any collider at that time could produce – they simply lacked the required energy.

It's fair to say that the W boson discovery would have been impossible without one of particle physics' most colourful and controversial figures: Carlo Rubbia. Known for his 24/7 dedication to physics and his aggressive nature, Rubbia travelled so often between Harvard and CERN that he was made an honorary board member of Italian airline Alitalia.

Along with Peter McIntyre and David Cline, Rubbia suggested that the key to producing W bosons was to create, collect and accelerate antimatter and smash it into matter, a process that would produce W bosons in abundance if the energy was sufficiently high. An early proposal to adapt a proton accelerator at Fermilab for this purpose led to its director dismissing Rubbia as a "jet-flying clown", and the project was instead adopted at CERN – after much bullying and cajoling from Rubbia.

A Dutch accelerator physicist named Simon van der Meer had a vital missing ingredient called "stochastic cooling". This technique, which van der Meer had initially dismissed as too far-fetched, was essential for nudging protons and their antimatter equivalents into tightly focused beams. Working together, van der Meer and Rubbia led the charge on CERN's Proton-Antiproton collider, whose detectors UA1 and UA2 both saw W bosons. The discovery of the W boson was finally announced in 1983. Rubbia later admitted that he was scared stiff the beams wouldn't work.

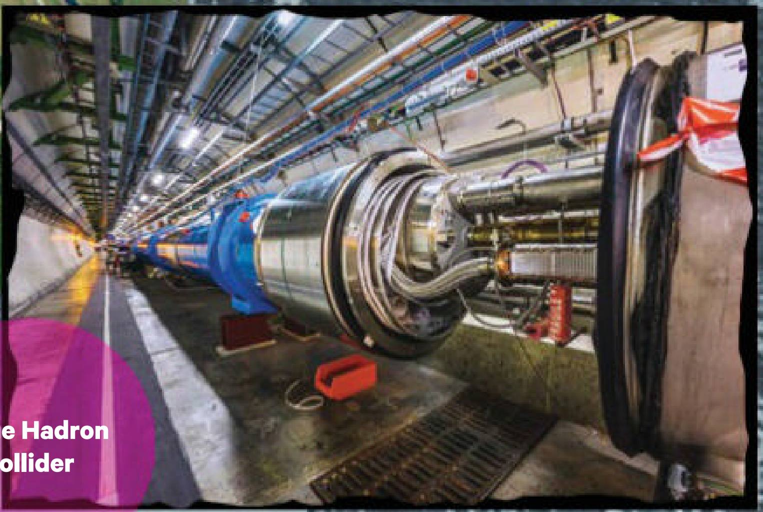
Understanding the properties of the W boson with more precision required yet more innovation in particle colliders. Colliding protons and antiprotons is excellent for particle discovery, because protons are dense mixtures of quarks and gluons. Each collision between a proton and an antiproton leads to some element of the proton interacting with some element of the antiproton, with an energy that can vary from collision to collision. This allows physicists to produce particles within the same collider at a range of possible masses, but it also means that the results are messy and complicated.

Once the mass of a particle is known, however, a cleaner way to produce it is to collide fundamental particles like electrons and anti-electrons at exactly the energy required to make a particular particle. This allows one to obtain much more precise and detailed measurements of the particle of interest. For this purpose, the next step at CERN was to build the Large Electron-Positron Collider, whose 27km circumference was Europe's largest civil-engineering project prior to the Channel Tunnel. Along with a massive tunnel, four giant halls were built to house complementary detectors that used different designs to measure the W and Z boson properties.

LEC: JEFF J MITCHELL/GETTY IMAGES. ADAPTED FROM PETER CROWTHER

2003 Tevatron by Fermilab

Champagne bottles mark CERN breakthroughs


Large Hadron Collider

2000s

Across 11 years beginning in 1989, the most cosmopolitan and diverse teams that physics had ever seen measured the properties of the W and Z bosons of the Standard Model with superb precision, although the size and complexity of the machine pushed physicists well beyond the limits to which they were accustomed. Having already noted that the amount of water in nearby Lake Geneva and the orbit of the Moon had to be taken into consideration to understand the energy behaviour of the collider, scientists offered a bottle of champagne to anyone who could explain a strange disturbance that was observed at 8am, 11am to 1pm, and 6pm to 7pm. The prize was claimed by the first person who noted that the local TGV train timetable was the likely culprit, and for a while the LEP collider was the most accurate device for measuring the punctuality of Swiss and French trains.

By the early 1990s, only two pieces of the Standard Model remained unobserved. The top quark was finally discovered in 1995 by the Tevatron, a proton-antiproton collider based at Fermilab whose two experiments – D0 and CDF – were able to determine the mass of the top quark to a precision of roughly one per cent. The Tevatron ceased operation in 2011 due to its inability to compete with the Large Hadron Collider, CERN's current flagship that remains the highest energy accelerator in the world. The D0 and CDF collaborations, however, have continued to develop their software and analyse the data in increasingly precise ways, a process that can often extend the life of an experiment by over a decade.

Active between 1983 and 2011, the Tevatron at Fermilab (above, left), in the US state of Illinois, was the discovery site of the Standard Model's top quark. Although the 6.28km circumference Tevatron closed in 2011 partly because the more powerful LHC (above) had been commissioned, further analysis of its accumulated data this year yielded the stunning new measurement of the W boson. At the LHC's home, the CERN complex, significant milestones are marked (above top right) on champagne bottles. Beyond the LHC, CERN's Future Circular Collider (opposite top) study is working on designs for higher energy particle colliders that may discover new physics in the 2040s and later.

Smashing protons together in the old LEP tunnel, the LHC has thus far taken only a 10th of the data it's expected to yield before it ceases operations in the late 2030s. Almost 10,000 scientists have been busy there measuring the properties of the W, Z and Higgs bosons, searching directly for new particles, and measuring a heap of particle properties to understand what might be next.

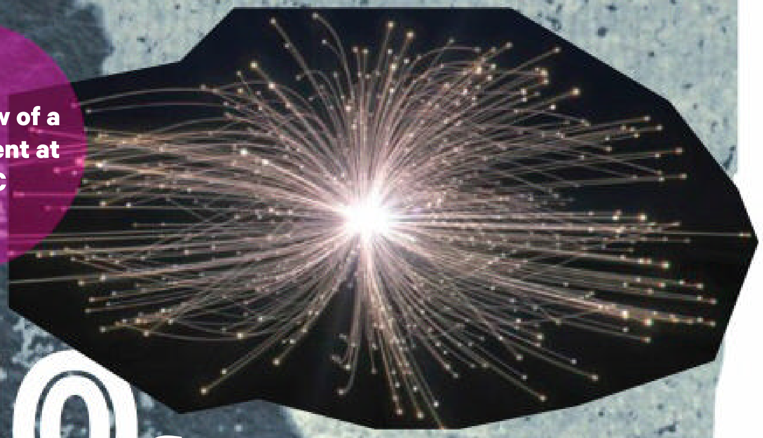
An unexpected guest at a family gathering

Before April of this year, measurements of the W boson were like a polite family gathering, with different experiments generally agreeing on the value. A surprising announcement from the Tevatron seemed about as likely as a new Abba album, but 7 April saw the release of a new W boson measurement by the CDF collaboration that has an awe-inspiring precision relative to previous measurements (*see page 36*).

The measurement is not only significantly higher than the value expected in the Standard Model given our knowledge of other particle properties, but is notably higher than other previous measurements. This includes one made by the other experiment at the Tevatron, D0.

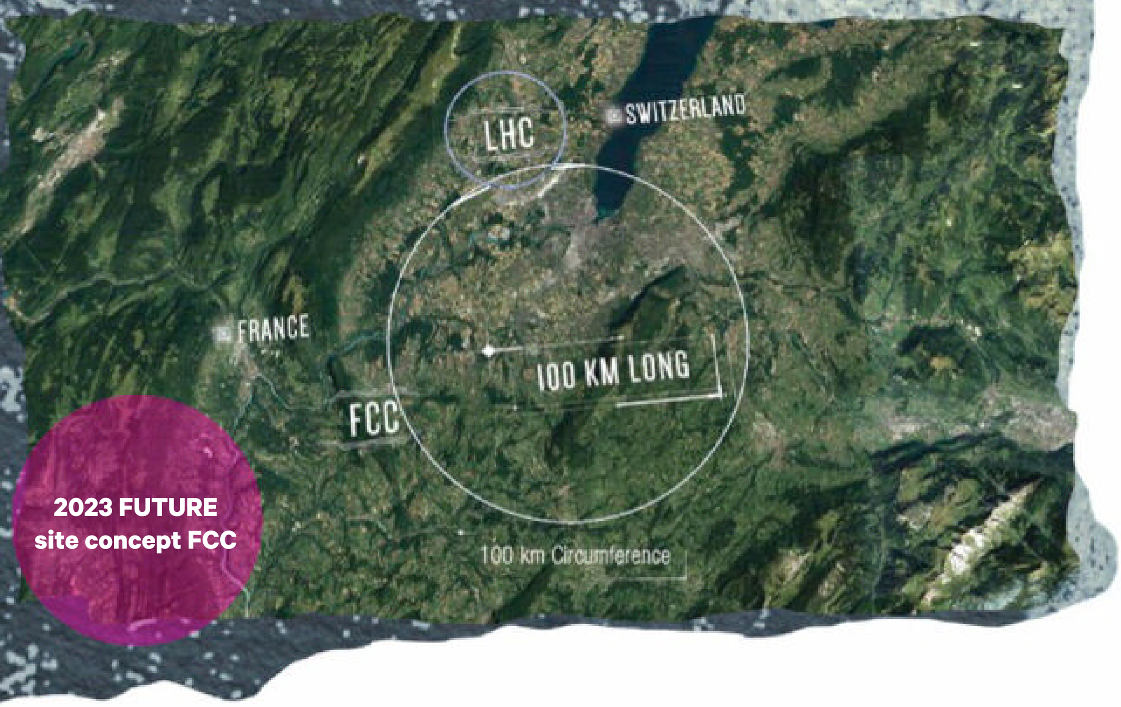
The impact on physics has been immediate, with many theoretical physicists losing sleep to rush out explanations of which new particles could explain the result. MIT-based Nobel Laureate Frank Wilczek perhaps summed the situation up best, telling *Quanta* magazine on 8 April that the measurement is "a monumental piece of work, but it's very hard to know what to do with it".

FROM LEFT: FERMILAB REIDAR HAHN. CERN. DEAN MOUHTAROPOULOS/GETTY IMAGES



Artistic view of a collision event at the FCC

2040s



2023 FUTURE site concept FCC

CERN X2

The next decade of particle physics now looks vastly different. But there's an obvious question. If all other results are consistent with a different value, is it possible that the CDF measurement includes mistakes?

There are in fact good reasons why the CDF collaboration should be able to make the world's most precise measurement of the W boson mass.

First, the Tevatron collided protons and anti-protons, instead of protons and protons as the LHC does, and it turns out that this makes W boson production easier to understand. It's also true that the lower energy of the Tevatron helps measurement precision relative to the higher energy of the LHC, since we understand the collisions slightly better at those lower energies than at higher energies. Finally, the LHC collides protons far more often by smashing bunches of protons together with high frequency. Whilst useful for making rare processes happen more often, this has the effect of creating many overlapping collisions that make it much harder to find and study particles of interest.

The Tevatron thus has some genuine advantages, quite apart from the fact that a scientific team such as the CDF collaboration has a much greater understanding of its machinery and data towards the end of its experiment than a team that is still working to understand their equipment. If nothing else, the struggle to understand the CDF result will cultivate an understanding of fine details that will enhance all future measurements of the W boson and other particles.

Second, can other experiments update their measurements to try and confirm the result? The most obvious contender is the D0 experiment, which can analyse proton and anti-proton collisions similar to the CDF's. Over the next few years, the ATLAS, CMS and LHCb experiments can also try and update their results with new data, and can try and unpack differences in their work that may explain the anomaly.

The road is hard and fraught with danger, however. The recent ATLAS measurement struggled with an unexplained effect for months until it was finally discovered that the distortion over time of the detector under its own 7,000 tonnes of weight is a significant factor in the final result.

Finally, there is the Nobel-worthy prospect of new particles to consider.

The great Formula 1 driver Ayrton Senna once said: "If you no longer go for a gap which exists you are no longer a racing driver". The physics equivalent is "If you no longer try and explain a particle anomaly, you are no longer a physicist". A shift in the W mass turns out to be almost embarrassingly easy to explain, for example through the existence of extra Higgs bosons, or through the existence of a new symmetry of nature called supersymmetry, which is among the most studied of particle theories.

Intriguingly, many of these explanations could also explain other known anomalies, such as muon measurements that don't quite match the Standard Model prediction. Work is underway at the University of Adelaide and elsewhere to thoroughly explore the landscape of options that explain the result, and work out how to perform other tests of these theories that might clarify the situation sooner rather than later.

Kelvin vs Michelson

The 19th-century scientist who came closest to actually saying that physics was done is almost certainly Albert Michelson, the Prussian-born physicist who in 1907 became the first American to win a Nobel Prize in a science. Michelson declared that "while it is never safe to affirm that the future of Physical Science has no marvels in store even more astonishing than those of the past, it seems probable that most of the grand underlying principles have been firmly established".

In the modern era, the irony of this statement isn't limited to the fact that Michelson failed to anticipate the scientific revolutions of his own lifetime. It's instead enhanced by the fact that it is only by making more and more precise measurements that we will reveal the next grand principles of nature.

The revised W boson mass measurement suggests that the prospects of doing just that have received a major and totally unexpected boost. ⊛

MARTIN WHITE is a particle physicist and professor at the University of Adelaide. His last story, on particle modelling, appeared in Issue 88.

HUMAN-CENTRED SOFTWARE

A world-first research project aims to build software tools that respond to the full spectrum of human traits and demographic factors, rather than just those that dominate. The lack of diversity in software developers and ironing out industry-wide inefficiencies are just two of the issues to address, writes **BRON WILLIS.**

KLAUS VEDFELT/GETTY IMAGES

How can we empower domestic workers in Bangladesh? How do we increase job applications from females in the Oregon IT industry? How can we help a technology-illiterate grandmother from Melbourne buy wool during a pandemic? And how can we respond to the emotional needs of someone who has recently received a terminal diagnosis?

These are just a few of the questions that software developers and researchers from Monash University's recently launched HumaniSE Lab have found themselves grappling with in the first two years of their world-first project. The project has the potential to vastly improve opportunities and experiences for a broader range of users, particularly disadvantaged users, as well as increasing the cost-effectiveness of software development across the globe.

"Software was – and overwhelmingly still is – developed by highly educated, relatively affluent, young men," says HumaniSE lab director Professor John Grundy. "And yet it has become ever more apparent how different we, the end users of that software, all are.

"It's not surprising then that a large number of people have problems using it."

The five-year project aims to put "humans at the heart of software engineering" by creating "intelligent, human-centred future software systems" that take people's unique qualities – such as age, culture, gender, cognitive ability, emotions and personality – into account.

Professor Grundy has been developing software for more than 40 years and witnessed the problems experienced by users of early software products in the 1980s.

"They'd spent all this money on developing software, only to have to spend a lot more fixing problems that hadn't been identified early on. It became hugely expensive, as well as leaving many users behind or excluding them altogether."

The project, funded by the Australian Research Council's Laureate Fellowship, includes international collaborations with organisations such as Oxfam Australia and Oxfam Bangladesh, the Alfred Hospital, the University of Oregon (US), and Arken University (Germany). The diversity of users these organisations need to reach provides a unique opportunity to test and develop modelling, tools and processes for future software engineers.

Monash University research fellow Dr Jenny McIntosh is leading the digital health area of the research and sees huge potential for reducing health costs by better meeting the needs of a broad range of individual users.

"Digital health is a multi-billion-dollar industry that is increasing exponentially," says McIntosh. "But it's also incredibly inefficient. If we can nurture health through simple digital solutions, we could save so much money."

> "SOFTWARE WAS – AND OVERWHELMINGLY STILL IS – DEVELOPED BY HIGHLY EDUCATED, RELATIVELY AFFLUENT, YOUNG MEN. AND YET IT HAS BECOME EVER MORE APPARENT HOW DIFFERENT WE, THE END USERS OF THAT SOFTWARE, ALL ARE."

McIntosh offers the example of a software tool that helps identify risks involved with diabetes – both in terms of preventing diabetes and also managing risks of those diagnosed with the disease.

“If a digital tool can help a pregnant woman, for example, better assess their risk of getting gestational diabetes, they can then take action to minimise that risk. And it’s not just the woman that benefits,” she says.

“If people can self-manage their health risks, that’s going to take pressure off the health system as well as empower people to manage their own health.

“A digital tool could also help assess a person’s risk of type 2 diabetes and ideally prevent it, which means a huge amount of taxpayers’ money – that would otherwise be spent on medication, surgery and, down the track, perhaps even cardio-vascular disease treatment – can be saved.”

Grundy also points out the vulnerability of many users in the health setting.

“This group is about as diverse as you can get,” Grundy says. “They’re often stressed at the time that they access technology and they might have sharp emotional reactions that poorly-designed software can exacerbate.”

Another area HumaniSE sees huge potential in is the finance sector.

“There is a real worry about the impact the digital divide is having on those less able to access digital finance tools,” says Grundy. “There are vulnerable people who might have older phones that new apps don’t work on. Many developers will make assumptions about users that don’t apply to this part of the community.”

The HumaniSE Lab aims to address this by investing much more heavily in the research stage of software development.

Dr Tanjila Kanij is a research fellow on the project and says that investment in research during software development is a trade-off – because although it’s expensive, it pays off.

“If you miss out on a certain type of user, you lose the benefit of reaching that audience. In my opinion, it’s a viewpoint change that outweighs the extra investment.”

Kanij’s research is attempting to reach domestic workers in Bangladesh through an international collaboration with Oxfam Bangladesh. These users face challenges with literacy and accessing fair-work environments. Kanij sees significant potential for software to empower these workers as significant.

“There are a huge number of domestic workers in Bangladesh, but their work is not well recognised,” Kanij says. “As a result, they don’t have set working hours or leave and they’re vulnerable to abuse by employers who have control over their employment and often their living situation. Our goal is to empower these domestic workers with digital technology.”

Two aspects Grundy considers crucial are the effectiveness of tools created by the software, and the diversity of the software engineers creating those tools. The HumaniSE research team includes an unusually high proportion of women.

“You might be surprised to know that there was a higher percentage of women working in software development 40 years ago than there is now,” he says.

Kanij agrees.

“There are unfortunately not a lot of women working in the industry,” she says. “Even in university software development courses, women are a minority.”

Australia’s Digital Pulse Report 2021, published by the Australian Computer Society, reported that only 25% of workers in the technology sector are women.

According to McIntosh, a culture of diversity is both a way of working and a goal in itself.

“We’re a very diverse team,” she says. “There’s a lot of unconscious bias that we fight against, so we can use our own personal experiences to inform the project.”

Measurement of this bias is something that has not been attempted before, but which the project aims to create a tool for.

“We’re trying to develop scientific methods to measure and improve diversity through software,” says McIntosh.

One example of these tools is GenderMag (gender magnifier), which has already been used at the University of Oregon. The tool helped to create software engineering job advertisements that address uneven gender representation in the workforce, caused by job advertisements being biased towards men.

“One of our recent studies has shown that men have a different approach to seeking and reading IT job advertisements than women,” says Grundy. “If job advertisements are skewed towards this, then the workforce will continue to be dominated by men, which then continues the cycle.”

The lack of diversity goes further than just gender, too.

“We have problems with ageism in the software engineering workforce,” says Grundy.

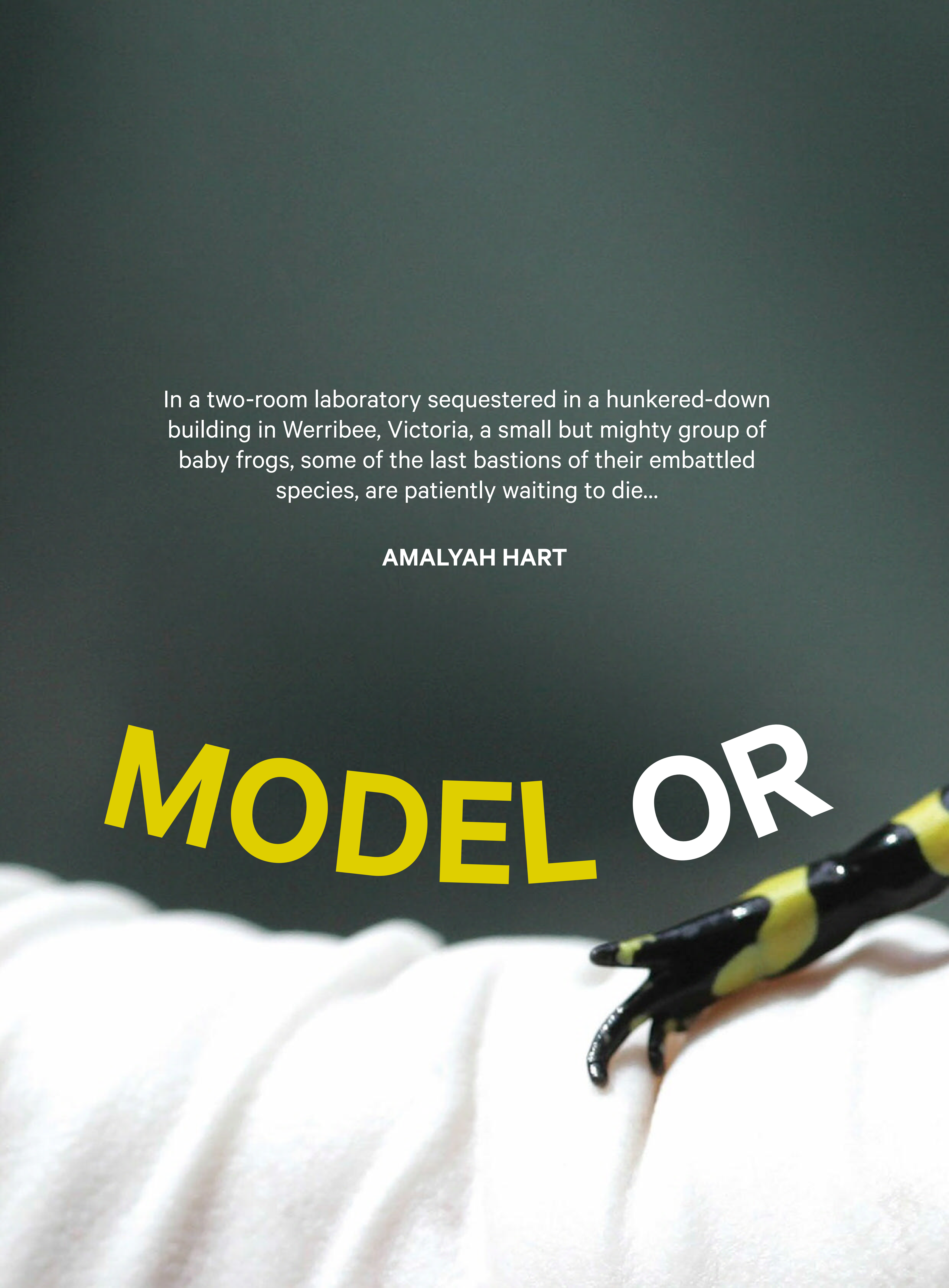
“We have problems with different cultural backgrounds not being appreciated; neurodivergent people and people with physical challenges are also not well integrated or supported. This leads to a lack of diversity.”

HumaniSE Lab aims to address all these challenges by diversifying the software engineering workforce and understanding software users more deeply. The project will continue for another three years.

BRON WILLIS is a freelance environment, science and sustainability writer based in central Victoria.

Read more like this at
thecosmosweekly.com
Where the rubber of science
meets the real-world road.

KLAUS VEDFELT/GETTY IMAGES



MODEL OR

In a two-room laboratory sequestered in a hunkered-down building in Werribee, Victoria, a small but mighty group of baby frogs, some of the last bastions of their embattled species, are patiently waiting to die...

AMALYAH HART

MONSTER?

GARY RAMAGE/TARONGA ZOO

I've come to visit them on a blinding hot February day, and I've been excited about the encounter for weeks. But when I open the door and see them, squatting blithely in row upon row of plastic tanks, I'm struck with a potent wave of tragedy.

These are juvenile southern corroboree frogs, tiny little things with an overlaid pattern of bright yellow and black on their breathable skin, like a croaking nuclear waste sign. That's pertinent, because they secrete a poisonous alkaloid through that skin that can kill prospective predators.

I squat on my haunches, greeting one of the little frogs as it hovers, suction-cup toe-pads pressed against the glass, its little throat moving rhythmically up and down. It has no idea what's coming.

These young frogs, some no bigger than the tip of my thumb, are doomed – they won't live for more than a few months at most. But their deaths may be the key to reversing the march of their species towards extinction.

That's because these frogs are the first test subjects in a project that will plumb some of the most exciting (and controversial) realms of science, in the quest to conserve a dying species – by striding into the vanguard of gene editing.

Lee Berger was in the midst of her PhD at James Cook University in the 1990s when she began investigating an alarming and inexplicable global decline in amphibian populations that had been going on for at least 20 years. At the time, its effects were seen most acutely in the rainforests of Central America and Queensland.

Mass frog deaths were moving across the landscape, following the kinds of patterns you expect from an epidemic, and researchers were proposing that some sort of exotic pathogen must be behind the deaths. But it was Berger who, in 1998, first identified a fungus, *Batrachochytrium dendrobatidis*, suffusing the skin of sick frogs.

Southern corroboree frogs are native to the mossy sphagnum bogs of the northern Snowy Mountains, and are exclusively found within the limits of Kosciuszko National Park. They summer in mossy chambers, where the males voice a charmingly offbeat 'squelch' to attract their mates. In the winter, they retreat to the snow-sheltered undersides of snow-gum logs and leaf litter.

Southern corroborees are now functionally extinct in the wild, because *B. dendrobatidis* causes a ravaging disease known as chytridiomycosis. According to Zoos Victoria, there may be fewer than 50 of these frogs left in their natural habitat, and the tiny group remaining only persists because breeding programs have periodically replenished their dwindling population.

B. dendrobatidis, also known as the chytrid fungus, takes advantage of amphibians' most important evolutionary quirk – their porous skin. "Frogs actually absorb oxygen through their skin, and they also absorb a lot of electrolytes that way," explains Tiffany Kosch, a research fellow at the University of Melbourne and one of the lead architects behind a daring new plan to save the frogs.

"So, how the fungus ends up killing them is they actually have a heart attack, because they're not able to maintain the correct electrolyte balance in their bloodstream, so the heart slows and they eventually die."

And the chytrid fungus is a serial killer: by some estimates, it may be responsible for the greatest disease-driven loss of biodiversity in recorded history. It travels in water, spreading through interlocking stream systems and from frog to frog, decimating the populations it comes into contact with.

In the Melbourne research lab, I'm introduced to chytrid by the scientist who first illuminated its crimes. More than 20 years on from her initial discovery, Berger is now working in the same facility as Kosch where, in a small fridge in the next-door room, she carefully stewards petri dishes of the murderous fungus.

LEE BERGERS

WHAT IS CHYTRID?

Globally, at least 200 species of frogs have either declined catastrophically or been wiped off the face of the earth by chytridiomycosis.

In Australia alone, the fungus has brought about the decline of at least 43 of the country's 200 frog species.

Seven Aussie species are now thought extinct, including the sharp-snouted day frog (*Taudactylus acutirostris*), a stylish brown miniature with a racing stripe down its side, whose last remaining population, hiding out in the upland rainforests of North Queensland, disappeared in 1993.

Combined with the impacts of climate change, urban expansion and the introduction of the invasive cane toad, Australia's frogs face an existential threat.

She takes one out, places it under a microscope and invites me to look.

Tiny little swimmers dart around on invisible flagellae, dodging bigger, globule-like cells that hover, suspended in the artificial light.

The swimmers are the infective cells, which latch onto the frog's skin and begin to multiply, transmuting into the fat globules that clog the frog's life-giving pores. Looking at these tiny cells, floating inoffensively on the microscope's plate, it's hard to believe they could wreak such ecological havoc.

The chytrid fungus has resisted more than two decades of efforts to remove it, and the disease kills around 95% of the southern corroborees it comes into contact with. Kosch and her team at Melbourne University are aiming to reverse this seemingly intractable situation, by armouring the frogs with a set of genes that might protect them.

This will require one of two approaches. The first option is artificial selection: breeding creatures with the necessary genes together to produce a resistant population over several generations. Humans have been practicing artificial selection for millennia, ever since the first domesticated crop or tamed wolf.

The second approach is a bit more controversial. Synthetic biology is an umbrella term for a number of techniques that manipulate genes or sets of genes to achieve a desired result.

These include transgenesis, which involves transferring whole genes (or sets of genes) into one species from another species, and gene-editing, which involves 'snipping' out certain genes (or parts of a gene) and replacing them with others.

Synthetic biology can alter an organism's genotype (its genetic material) to produce a desired phenotype (the observable traits coded for by the genotype).

"So many of these frogs are now bred in captivity, but whenever they release the frogs they usually don't survive, because the pathogen can't be eradicated," says Kosch. "So, our idea is to test synthetic biology methods, which are very successful in agriculture, and see if they might work for conservation."

About 10,000 years ago, as the last ice age relinquished its grip and *H. sapiens* stood on the threshold of the Neolithic, archaeologists think that a handful of communities living between the Tigris and Euphrates rivers in Mesopotamia (modern day Iran, Iraq and Syria) began to play around with the seeds of wild plants, purposefully selecting and planting them for a predictable crop, and the certainty of food. In doing so, they could not have known that their selective choices would alter the genomes of entire species.

The agricultural revolution completely reshaped the structure of human life, enabling more permanent settlements and larger communities. And the crop plants that would emerge became both genetically and phenotypically distinct from their wild counterparts.

Successive civilisations have been meddling with DNA for millennia. What makes synthetic biology so different?

Current gene editing techniques allow scientists to make the kind of changes in a single generation that might once have taken many iterations of environmental trial-and-error. Proponents argue they also allow for much more precise changes.

"The really good thing about gene editing, compared to artificial selection, is you're only changing the genetic elements that you're trying to change, not a whole bunch of other things," explains Kosch.

"And that's really important, because we want these frogs to be able to survive in the wild in future. And because we don't know what these frogs are going to be experiencing in the future, we have to preserve their genetic diversity."

"Whenever you have a technology that's really, really powerful, you can use it to do really good things, but you might use it to make big mistakes. That's the crux of this issue, we've got this power now, and we have to decide how to use it.”

But that also makes it an impressively powerful tool, in the hands of a species that has not always been judicious.

"Whenever you have a technology that's really, really powerful, you can use it to do really good things, but you might use it to make big mistakes, or some people might use it with bad intentions," says Christopher Gyngell, a bio-medical ethicist at the Murdoch Children's Research Institute who has worked extensively on the ethics of gene editing.

"That's the crux of this issue, we've got this power now, and we have to decide how to use it."

For Gyngell, the important thing in this type of research is to be slow, cautious, and reasoned.

"I think you need to be careful with these technologies, you need to move slowly," he says. "What human history has shown us is that ecosystems are really complex, and sometimes humans don't understand them as well as we think we did."

Agalychnis moreletii; >90% decline

Ranoidea nyakalensis; confirmed extinct

Atelopus angelito; presumed extinct

Allobates olfersioides; presumed extinct

Agalychnis annae; >90% decline

Anaxyrus baxteri; confirmed extinct

> **"By looking closely at the genomes of the survivor frogs, the team hope to identify the genes affording them resistance to the pathogen. 'This might be hundreds of genes, maybe thousands, or it may just be a few. At this point, we really don't know.' "**

One of the core criticisms of using gene-editing in conservation, according to Kosch, is the idea that it's a band-aid over the problem, and that scientists and conservationists should instead focus on eradicating the threat.

The problem is that many of the threats to biodiversity around the world are now rampant – a Pandora's box of dire consequences.

Limiting global warming now won't stop or reverse its consequences for decades, at best. It's the same with chytridiomycosis.

Scientists have tried for decades to come up with ways to eradicate the disease, including expensive and dangerous chemical treatments with knock-on effects for other local species, and all to no avail.

From Kosch's perspective, then, the way to give this frog a fighting chance is to delve into its genes.

Only a few weeks after my first visit to the lab, I receive an email from Kosch: the experiment is underway.

The researchers have placed the frogs in little takeaway sauce cups. After pipetting a liquid mixture of water and chytrid fungus over them, they're kept in the containers for six hours, to allow the fungus to fully take hold. Then, over the course of the next few weeks, the team will observe how each frog is faring.

Kosch, like any good biologist, loves frogs, and she admits it's hard work to do. But she is focussed on the research she believes is the species' best hope of survival.

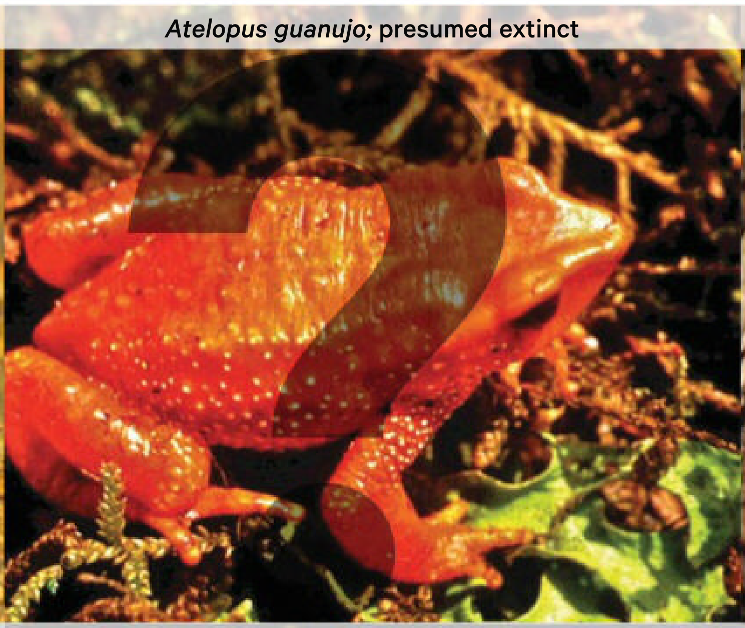
"Obviously we don't want to be causing frogs to die, but at the moment unfortunately a lot of these little guys are not going to survive if they're released into the wild," she says. "If we're doing something that can maybe increase their chances of survival someday, it's worth trying."

Around 95% of the frogs will die within a few weeks of infection. The first indication that something is wrong is a kind of limpid sluggishness, a reluctance to move. The scientists put a gloved hand into the tank: a healthy frog will hop away, but a frog sick with chytridiomycosis will stay put.

Another tell-tale sign is posture: a healthy frog will sit with its legs tucked underneath it, whereas

FROM TOP LEFT: CHESTER ZOO, AMPHIBIAWEB X2, RENATO AUGUSTO MARTINS, CHARLES J SHARP/WIKIMEDIA.
JEFF BAUGHMAN/CHEYENNE MOUNTAIN ZOO

Colostethus panamansis; >90% decline



Atelopus guanujo; presumed extinct

Atelopus pulcher; >90% decline

Atelopus balios; >90% decline

Nectophrynoides asperginis; confirmed extinct

Agalychnis lemur; >90% decline

FROM TOP LEFT: BRIAN GRATWICKE, FILIPE CAMPOS. NATURE CATCHER/WIKIMEDIA. INDICATOR_SPECIES/ REDDIT. JULIE LARSEN MAHER/WILDLIFE CONSERVATION SOCIETY. FROGMANIA/WIKIMEDIA

an unhealthy frog will splay its legs and struggle to climb.

In the final test, the researchers will take the frogs out of their tanks and place them upside down in the palm of their hand. A healthy frog will right itself, but a sick frog will lie there, helplessly supine. After this righting reflex is tested and failed three times, the frog will be euthanised.

The hope is that 5% of the frogs will survive infection and recover, and their DNA could hold the key. By looking closely at the genomes of the survivor frogs, the team hope to identify the genes that are affording them resistance to the pathogen.

"This might be hundreds of genes, maybe thousands, or it may just be a few," notes Kosch. "At this point, we really don't know."

But once they do know, the discovery will allow the researchers to work out how to arm new generations with the right genes that could help them survive in the wild.

So, do they use the old method or the new? Artificial selection or synthetic biology?

If the genes that code for resistance in these frogs are easily inherited, or involve many genes all of which have a small effect, they're likely to pursue selective breeding, because it may be easier to breed the genes into a new population than to snip and replace so many, low-impact genes.

If the genes have low heritability, or they involve fewer genes that each have a significant effect, Kosch says they'll likely opt for gene editing, using CRISPR-Cas9 (*see page 50*).

That's because, in this case, it would be more difficult to breed a resilient population, and also because gene editing is much quicker – artificial selection can take tens or even hundreds of generations for the positive genetic change to take hold.

Both methods have risks: selective breeding a small population can reduce genetic diversity, or could breed out other genes needed to survive in the wild. Inserting genes that carry markers for chytrid resistance, could add another unforeseen weakness.

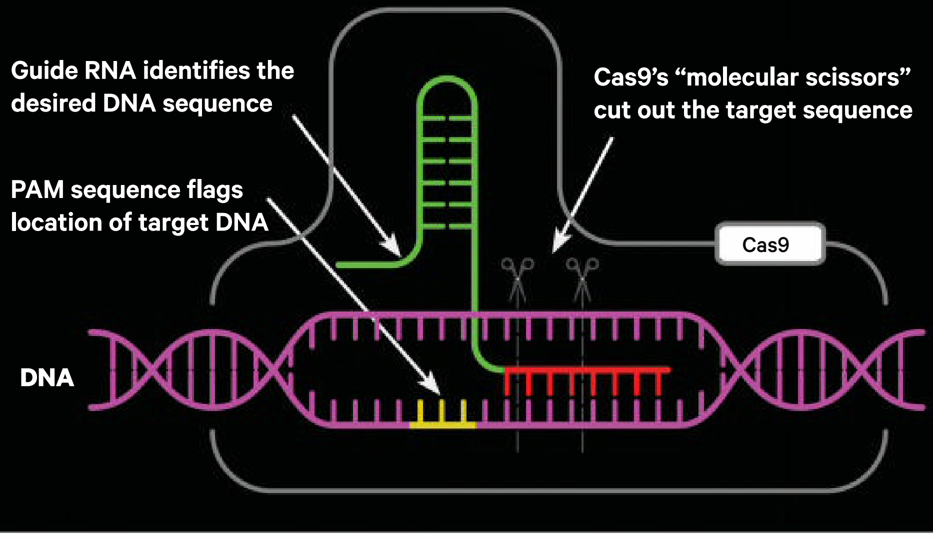
And there's another problem: releasing genetically engineered frogs into the wild is uncharted territory, so the methods they use will have to adapt as the regulatory landscape around this strange new world starts to take shape.

The chestnut tree is an icon of Americana; you'll have heard the Christmas song about nuts roasting on an open fire. The American chestnut tree was also a cornerstone species for local ecosystems up and down the US east coast for millennia.

"This tree was a very abundant mass producer," explains William Powell, director of the American

CRISPR

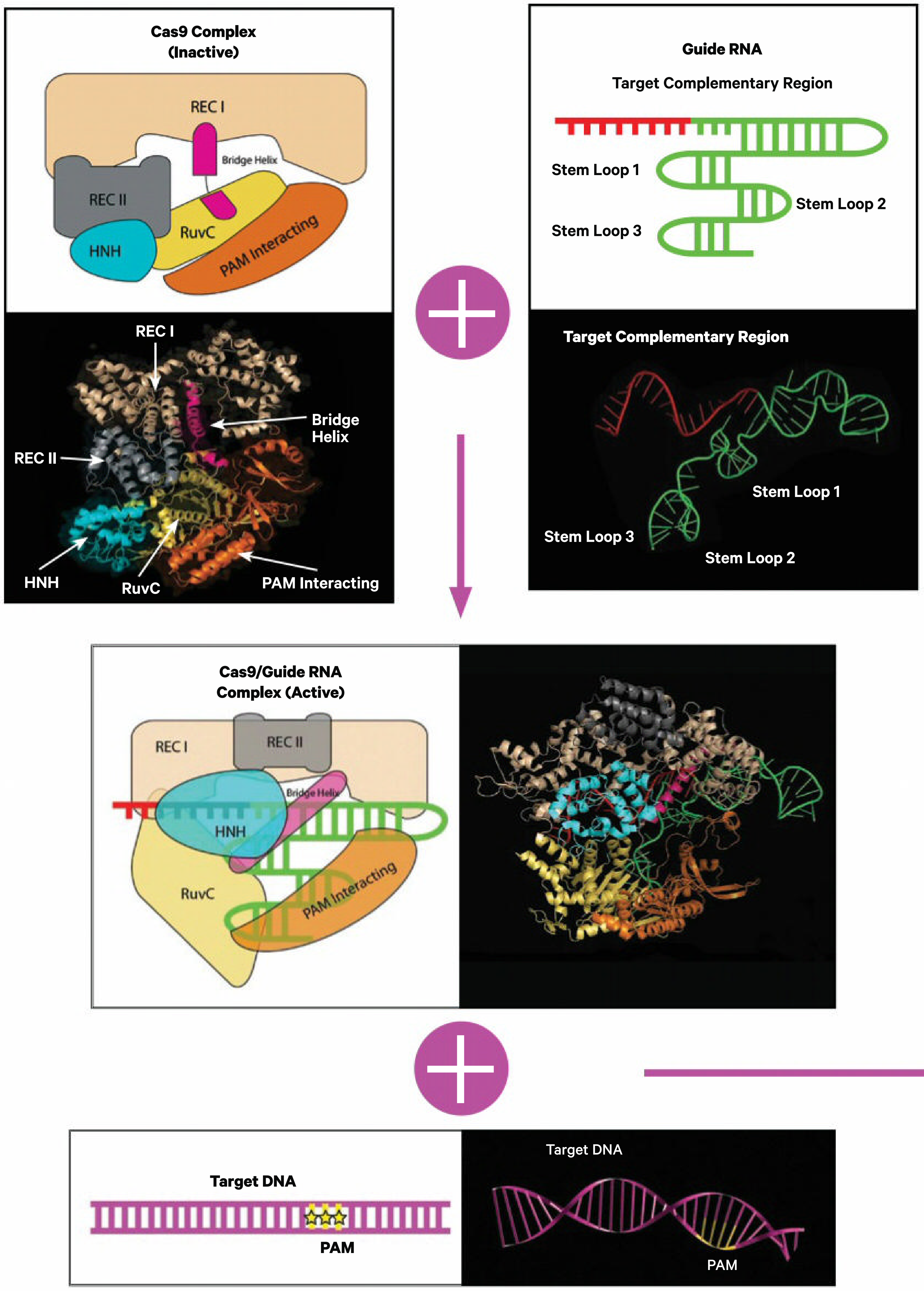
Gene editing by CRISPRCas9 is a now-familiar concept: guide RNA directs the Cas9 molecular scissors to “snip” the target DNA sequence for replacement with a new, stronger gene. It sounds (relatively) simple. But just how do the magical molecular scissors work?


Guide RNA identifies the desired DNA sequence
PAM sequence flags location of target DNA
Cas9’s “molecular scissors” cut out the target sequence
Cas9
DNA

CAS9: INSIDE THE MAGIC BOX

① Proteins such as Cas9 are made up of strings of amino acids which form certain structures – alpha helices (coils), beta sheets (flat ribbons) and joining loops. These structures combine to form domains, each of which have a particular function. Cas proteins are able to cut DNA at a specific sequence. In Cas9 the process begins when the largest domain, REC I (beige), binds to a guide RNA.

② When the RNA binds to Cas9 it changes the protein’s shape into an “active” form. Next Cas9 goes looking for a key section of DNA: the protospacer adjacent motif PAM (yellow stars). The PAM is a short sequence of DNA just two or three bases long near the target section. Another domain, the PAM-interacting domain (orange) binds to the PAM.



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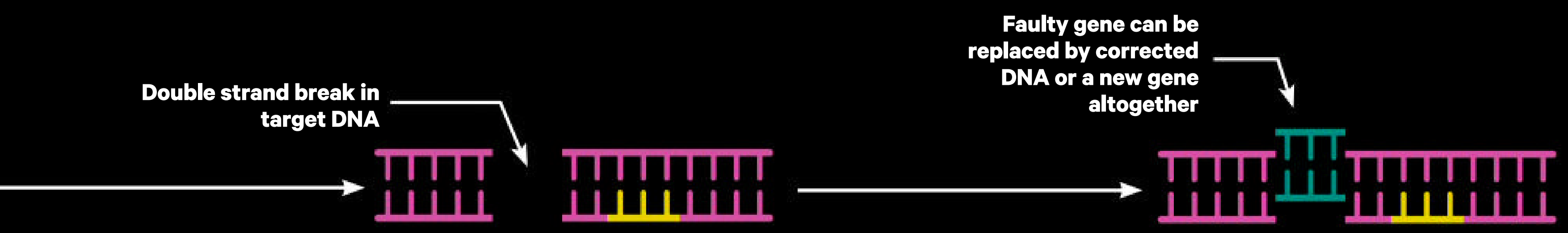
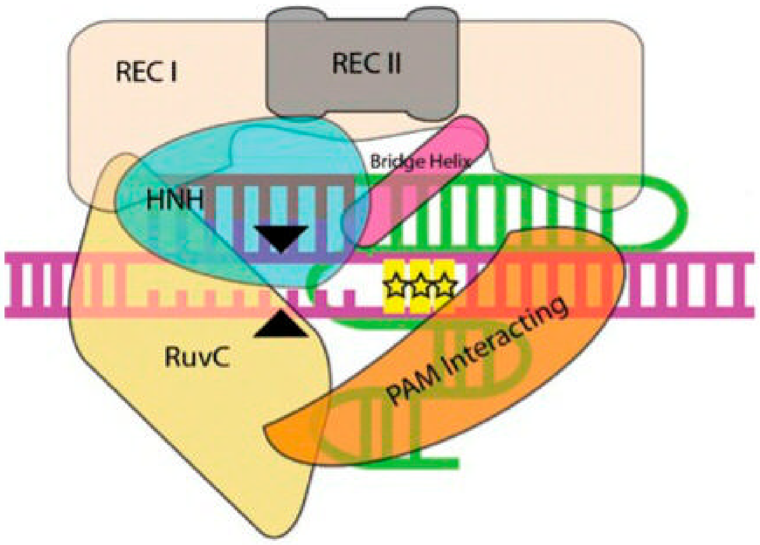
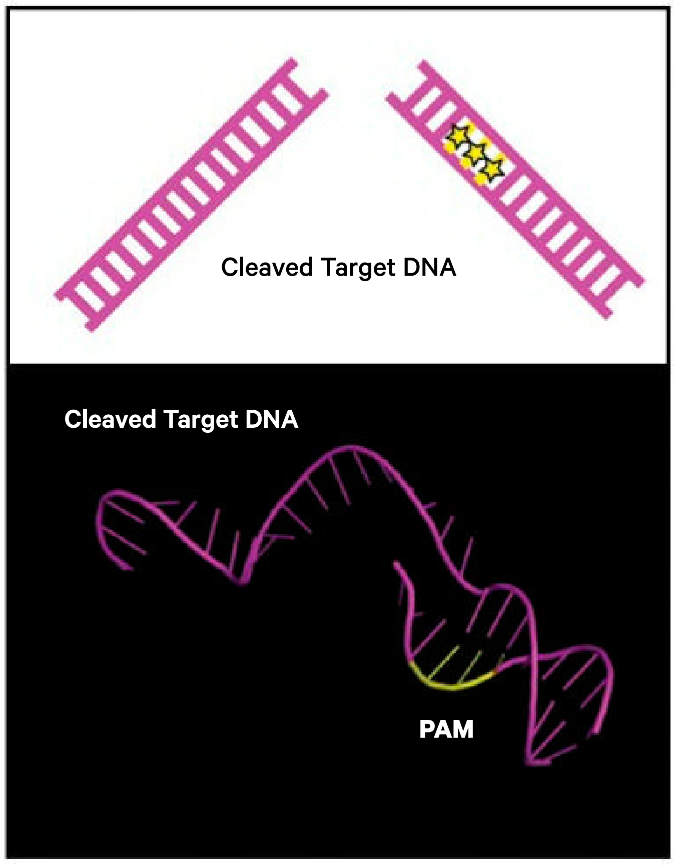
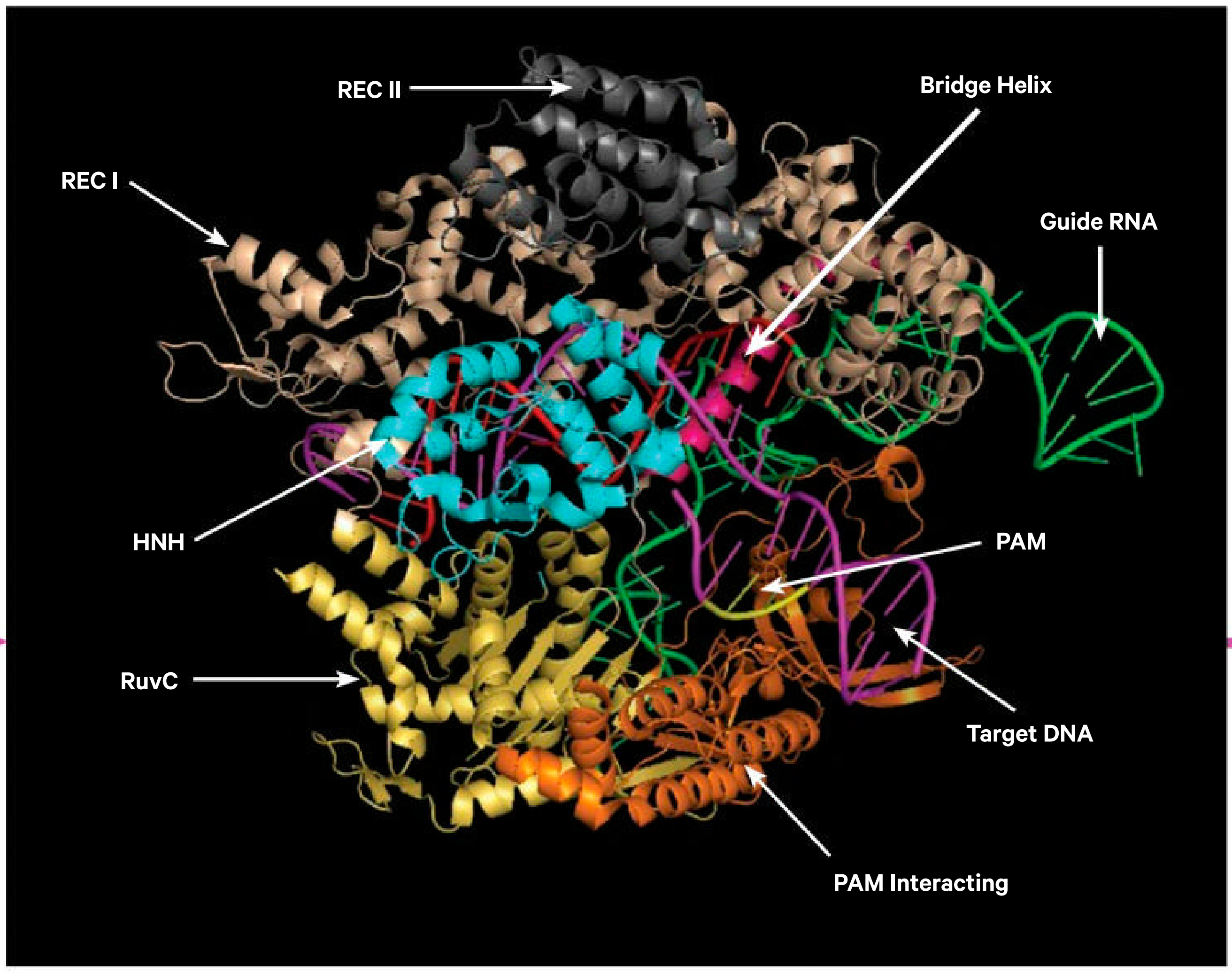

Double strand break in target DNA
Faulty gene can be replaced by corrected DNA or a new gene altogether

③ Once bound to the PAM, Cas9 will separate the strands of DNA near the PAM, and check if the DNA sequence matches the complementary region of the guide RNA. If the DNA is a good match, the HNH (blue) and RuvC (yellow) will cut or cleave the target DNA.

The bridge helix domain (magenta) also helps with the processes of binding the guide RNA and the target DNA and cleaving the target DNA. The function of some domains is better understood than others; the role of RECII (grey) in this process is not yet clear.







Chestnut Research and Restoration (ACRR) project at the SUNY College of Environmental Science and Forestry, New York, US.

“It produced a lot of nuts for wildlife [and humans] to eat, it produced really straight-grained, rot-resistant wood for people, and the leaves were used as medicine by Native Americans as well as early settlers.”

It’s a tree that provokes emotion for many of the people who live in its native homelands.

“It’s ingrained into our folklore,” Powell says.

But the chestnut has been all but lost to the east coast, thanks to another invasive fungal marauder – *Cryphonectria parasitica*, or chestnut blight. First observed on US soil in 1904 in the New York Zoological Gardens, the blight was introduced when people began importing the Asian chestnut tree into the country.

“They didn’t know at that time that when you bring a tree over, you bring all its microbes over also,” Powell says. While the fungus was a mildly annoying skin condition for the Asian chestnut tree, it spelled disaster for its American counterpart.

The fungus latches onto the tree’s bark and starts to gnaw a wound, called a canker, into the trunk or branch. It does this by producing a substance called oxalic acid, which kills off the tissue in front of it to produce a necrotising substance that the fungus can eat.

> **“Compared to traditional methods like hybrid breeding, it turns out this agrobacterium transformation causes ten-fold or maybe even 100-fold fewer changes to the genome than all those older techniques”**

The canker grows, eventually girdling the trunk or limb and cutting off the flow of nutrients; everything above the canker dies. If a canker forms at the base of the tree, everything above ground perishes.

It’s estimated that over the last century, four billion American chestnut trees have disappeared because of the fungus, with small pockets remaining in the Carolinas, West Virginia and in Pennsylvania.

Chestnut trees can survive at the roots, so there’s still a few million stump sprouts left. Periodically these stumps grow, encounter the fungus and die back, so the viability of a flourishing chestnut tree along the spine of the east coast is low.

But the existence of these stump sprouts means there’s a relative wealth of chestnut genetic diversity, so conservationists seeking to breed a new (and perhaps improved) population aren’t hampered by the problem that an endangered species tends to have: low variability in the population genome.

That’s where Powell’s research group comes in. For several decades now, Powell and his colleagues at the ACRR have been using genetic engineering techniques to alter American chestnut tree cells in the lab, with the goal of creating a tree that’s resilient to the fungus – and it seems to be working.

They’re utilising transgenesis, with a nifty little gene borrowed from the wheat plant. The gene produces an enzyme, oxalate oxidase, that detoxifies oxalic acid, breaking it down into carbon dioxide and hydrogen peroxide, two compounds the plant can use.

“And so, the nice thing is it doesn’t actually hurt the fungus at all,” says Powell – who is perhaps more charitable than me. “All we’re doing is taking the weapon away, so now it can live as a saprophyte [decomposer] on the tree, it can still cause a little bit of damage, but it’s not the severe damage where you get the whole tree being killed.”

They’ve transferred the gene into the tree cells using another handy bacterial tool, agrobacterium-mediated transformation.

“Agrobacterium is a bacteria that naturally genetically engineers trees or plants in general, and has been doing that for millennia,” says Powell. “So that’s what we did with the oxalate oxidase, we made what’s called a vector, put it into the agrobacterium, and then let the agrobacterium put it into the tree.”

Once the gene has been introduced, the researchers kill off the bacteria with antibiotics. This is all done while the tree is still in its cellular stage in the lab, so it’s tightly controlled.

The team have been field-planting these trees since 2014. But the next step – actually releasing them into the wild and populating the whole coast with its beloved chestnut once more – could take years of further regulatory hurdling.

“Those [field-planted trees] are all planted under USDA permits,” explains Powell. “And they come out and inspect our fields, we have certain rules to follow, and we can’t let them pollinate right now.”

At the moment, the program is under review by three agencies: the US Department of Agriculture (USDA), the Environmental Protection Agency (EPA), and the Food and Drug Administration (FDA).

Reviews for transgenic plants in the past in the US have almost exclusively focused on agricultural plants that are harvested every year; the chestnut, on the other hand, is not only a wild-dwelling plant but a long-lived tree.

The concept of changing an organism’s genes and then releasing it back into the wild is intrinsically Frankenstein-ish to some. Ever since scientists carefully unpicked the double-helix 70 years ago, DNA has been something of a godhead – an inviolable biological structure.

But that's not always how scientists see it.

"Part of the root of some scepticism is that there's something kind of integral and wholesome about a genome, and that that kind of defines what a being is," says Andy Newhouse, an ecologist and assistant director of the project at SUNY.

"But as we've been learning more and more over the past couple of decades about where our genes come from, they get swapped around all the time."

Some of this resistance may stem from a perspective that humans and other creatures are all separate entities, rather than a member of an interconnected community of organisms.

"There are so many genes in people, in plants, in chestnut trees and in corn from other stuff; from viruses, from bacteria, from related plants and unrelated plants," Newhouse points out. "So, I wish I could help convey that the genome doesn't define what a being is."

So, what do Powell and Newhouse make of fears about Franken-tree?

"If you actually look at this kind of agrobacterium transformation compared to older, traditional breeding methods like hybrid breeding, it turns out this agrobacterium transformation causes ten-fold or maybe even 100-fold fewer changes to the genome than all those older techniques," says Powell.

"And so, in reality, especially for conservation where you're trying to preserve the identity of certain species, it's kind of nice to have less of those changes."

The next time I visit the Werribee frog lab, there's a chill in the air. I slip on a pair of gum boots and a lab coat at the door so I don't unwittingly track the fungus out of the room and commit biological warfare against other frogs in the building.

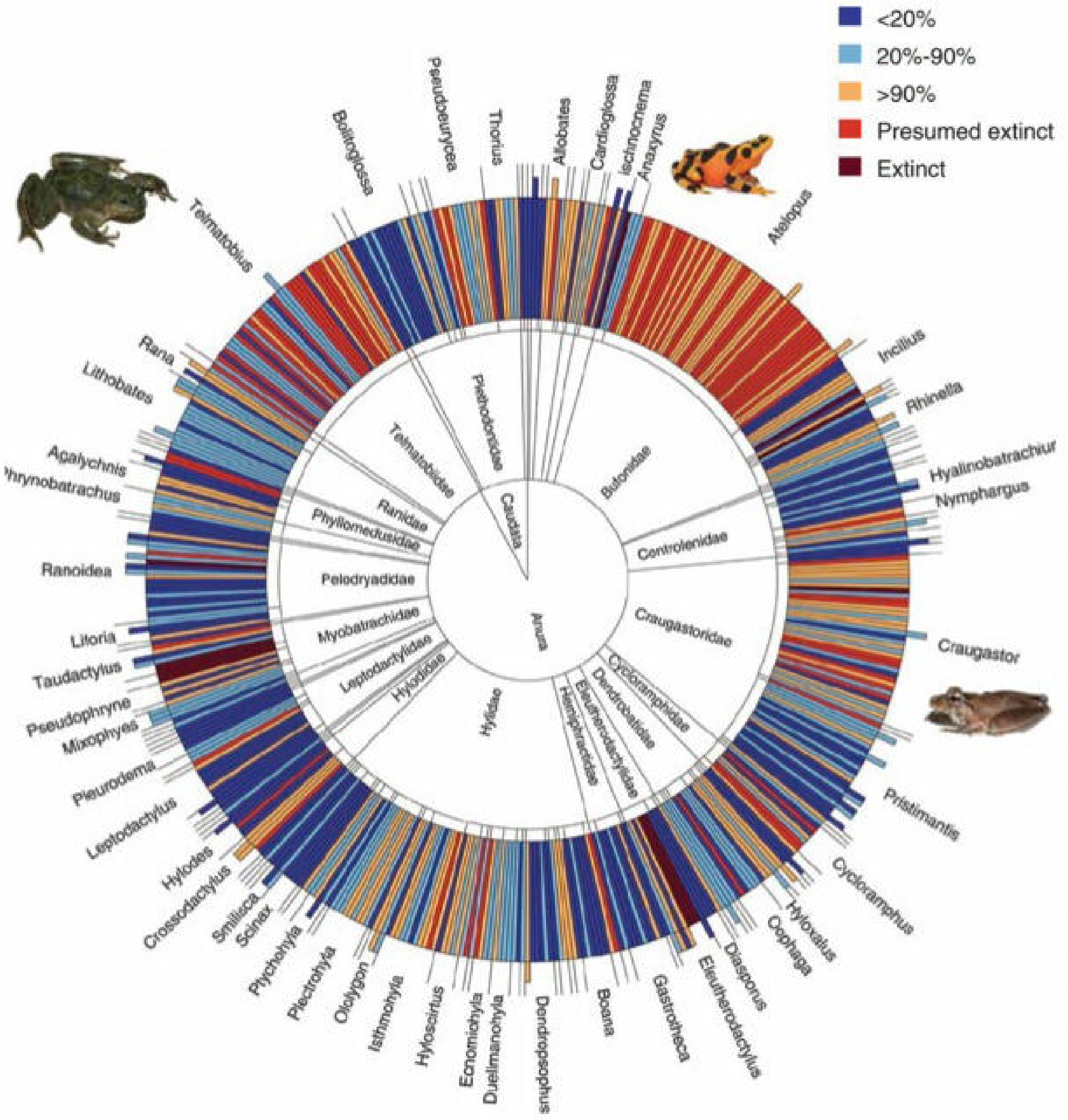
Of the 58 frogs I met before, just four are left – their lonely plastic tanks dwarfed by the empty shelf space where their comrades once sat. But there's a glimmer of hope to this otherwise sad story, because something quite remarkable seems to have happened.

One of the frogs – tank 27 – has escaped the inevitable. This frog doesn't seem to have contracted the disease at all, despite sitting in a liquid mixture of live chytrid fungus for six hours.

Given that Kosch only set out to identify frogs that could survive infection, the prospect of a frog that could actually be resistant to the infection itself is tantalising.

"We don't know if it's an anomaly or a super resistant frog, but it's a weird little thing," she says.

VICIOUS CIRCLE



Research by Scheele et al into the global effect of *Batrachochytrium dendrobatidis* – chytrid fungus – on 501 frog species. Each bar represents a species; colours show the extent of population declines. The researchers say their decline estimates are conservative for a number of reasons. They point to the large number of currently undescribed species in remote tropical ecosystems; their exclusion of species with documented declines but with no direct evidence linking that decline to chytrid; and a lack of data about many frogs' full range.

It's possible that somehow this particular frog was given a quantity of dead fungus – but Kosch says that's unlikely. The next phase of the study, then, will show them whether any other frogs have this mysterious super-resistance.

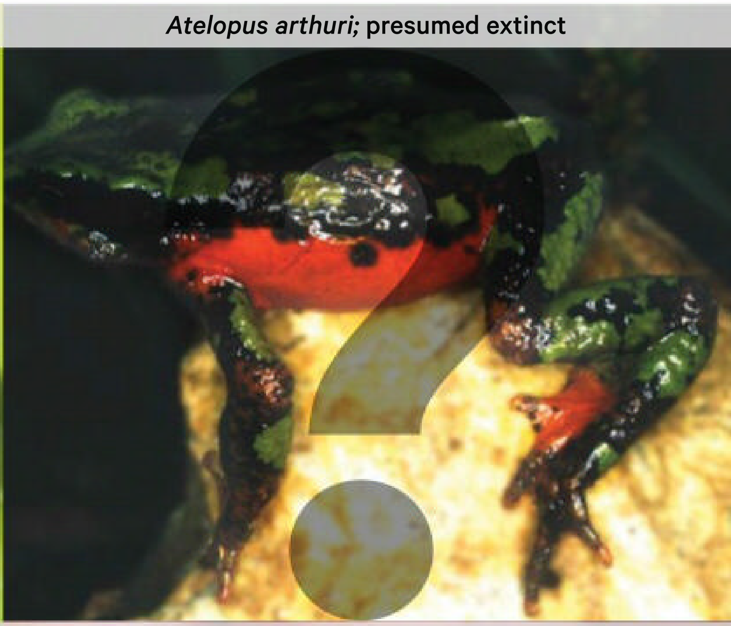
Apart from super-frog and his three dying friends, the other 54 all succumbed to the bug, and were euthanised when they failed the final reflex test. But Kosch and colleagues have painstakingly preserved tissue from every last one.

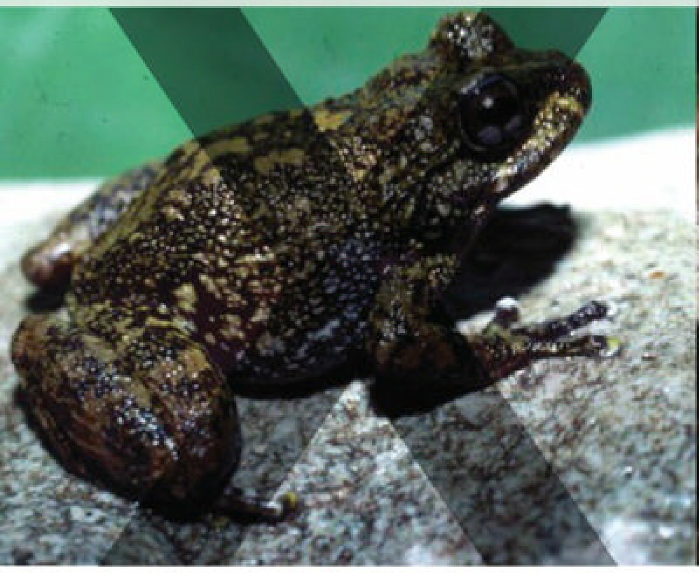
"We've kept the skin sections and we're going to study the skin and see if there's anything unique," she says. "Then, we're going to actually develop a genotyping method from the tissues of these frogs, so not a piece of them will be wasted."

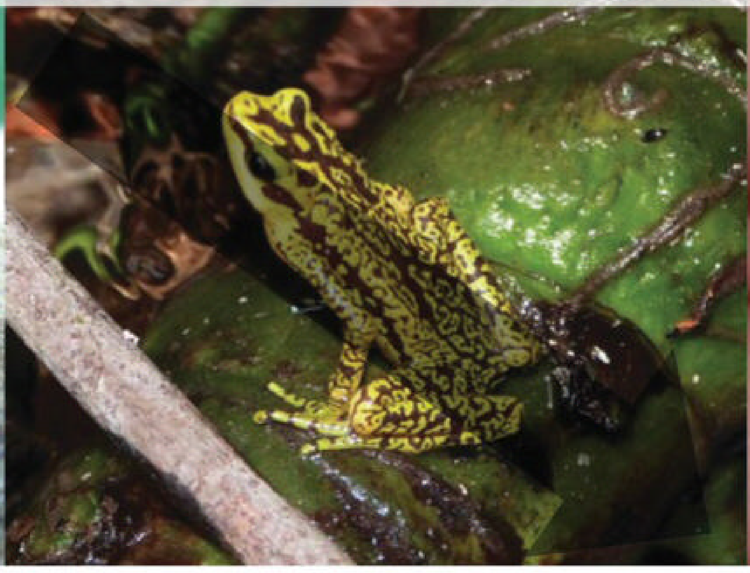
Genotyping is a technique that can detect mutations in DNA between individuals of the same

Atelopus boulengeri; presumed extinct

Atelopus bomolochos; >90% decline


Atelopus arthuri; presumed extinct


Craugastor chrysozetetes; confirmed extinct


Atelopus cruciger; >90% decline

Eleutherodactylus eneidae; confirmed extinct

species that can lead to major changes in the phenotype. Genotyping will be crucial in identifying which genetic mutations the resistant frogs share that might be transferrable.

There are all sorts of methods for genotyping, but in this frog-tissue pilot-study, the team hopes to use another cutting-edge tool.

"The most common method for wildlife is really crude, you basically just digest the genome with what are known as restriction enzymes, and then you look at certain sized pieces that remain and you sequence those to look for variation," Kosch explains. "So, you don't really have any control over what parts of the genome you look at."

SNP-ChIP is a bit different. SNP stands for single nucleotide polymorphism, which describes a change in the genetic code at the level of a single base pair on the genome – essentially the fundamental unit of the DNA double-helix. Base pairs contain a combination of two of the four nucleobases found in DNA – either adenine and thymine, or guanine and cytosine – which form the rungs on the double helix ladder.

> **"I don't think technologies are good or bad, it's how you use them ... we can just have this mentality that we need to protect our ecosystems, and we should be using whatever tools we've got at our disposal to do that."**

If a base pair is polymorphic, some members of a species may have that base pair at that location on the genome, while others will have a different base pair. It helps if you imagine the genome as a long metal chain: ten links into the chain some people might have a gold link, while others may have a silver link.

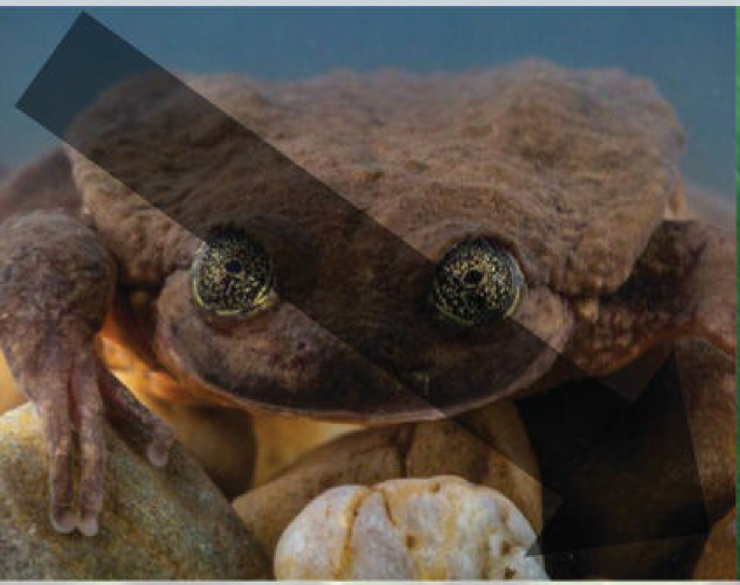
So, SNP changes are very small but very common – on average, an SNP occurs after every 1,000 base pairs in the genome (for reference, the human genome contains approximately 3 billion base pairs, while the southern corroboree frog genome contains three times as many).

The SNP method is thus more refined than other traditional genotyping methods

To identify the target SNPs on a the corroboree genome, scientists introduce synthetic, fluorescent nucleobases that bind to the corresponding bases on the DNA, flagging genetic variations and potential areas of interest.

If the frogs that survive chytridiomycosis share some clear SNPs, that will signal to the research team where their hunt should focus. If those SNPs are close to genes that are known in other species to code for

FROM TOP LEFT: AMPHIBIAWEB X3, J MCCRANIE. INDIANA CRISTO/WIKIMEDIA. EVA MATTHEWS.



Telmatobius yuracare; >90% decline

Incilius periglenes; confirmed extinct

Duellmanohyla uranochroa; >90% decline

Ecnomiohyla rabborum; presumed extinct

Atelopus certus; >90% decline

Rhinoderma rufum; presumed extinct

FROM TOP LEFT: ROBIN MOORE/GLOBAL WILDLIFE CONSERVATION. CHARLES H SMITH/WIKIMEDIA. MARCOS GUERRA/SMITHSONIAN INSTITUTE. BRIAN GRATWICKE/WIKIMEDIA X3

resistance to other pathogens, or sit close to genes known to code for an immune molecule like a T cell, that's another potential target.

Since there will likely be at least 50,000 SNPs per frog, they'll need a computer program to conduct statistical analysis to identify potential candidates. And even then, it's not perfect.

"There will be some [SNPs] that are found in the resistant frogs that have nothing to do with it, they just happen to be there," Kosch says. "So then you've got to try and rule that out as well."

It's going to be a complicated and painstaking process of elimination. But if they find that mutation needle in the DNA haystack, they might be able to save the species.

Whether you're nervous about Franken-frog or not, this kind of work is likely to become more common, as we enter the adaptive phase of our reckoning with the compounding impacts of climate change, habitat loss, and biodiversity collapse.

A million species are at risk of extinction, according to the UN. Most of these are disappearing because the equilibrium they evolved under is shifting. Oceans are warming, tree canopies are being replaced by arid grasses, rainfall patterns are growing or shrinking, fires are breaking their historic bounds. Change is coming. In many cases, change is already here.

So, do we owe it to the species we've imperilled to save them, by whatever means necessary? Or is this just another experiment in human hubris?

"In the face of more and more pressing threats, from climate, invasive species, other biodiversity threats, using all the powerful tools, including genetic engineering, is necessary," argues Newhouse.

Gyngell, within reason, tends to agree.

"My perspective on it is very technology neutral," he says, "so I don't think technologies are good or bad, it's how you use them.

"I think we can just have this mentality that we need to protect our ecosystems, and we should be using whatever tools we've got at our disposal to do that."

For the southern corroboree, which evolved in tune with its now threatened homelands on the Snowy Mountains – an area that was almost wiped out by the 2019-20 bushfires – things are looking dire. Without a pair of molecular scissors, argues Kosch, we might not be able to save them.

"If we want these frogs to be back in the ecosystem this is the only approach that has plausibility." ◉

An educational resource for this story is available at **www.education.australiascience.tv**

AMALYAH HART is a UK-based graduate of archaeology and anthropology and a former *Cosmos* journalist. Her previous story – on bio-inspired materials – appeared in Issue 90.

Loneliness: we all know the feeling of it, but it's hard to pin down precisely its causes and effects. Now, as **PAUL BIEGLER** reports, a growing field of study shows that this subjective feeling has objective effects – right to a cellular level.

ISOLA

On a cool night in the suburbs of Los Angeles in December, 1978, Jack Morris was at a house party. It was one o'clock in the morning and things were getting tense. Morris was 18 years old and hadn't long been released from juvenile detention.

"We were all drinking," he remembers. "Two guys went out into the back yard to fight, that fight ensued, and then the guy that was fighting said he didn't want to fight no more, and he ran into me, and he ran into another guy."

Morris is seated at his desk at the St John's Community Health Clinic in a squat brick building south of downtown LA, where he helps people who've left prison get jobs, housing, manage drug problems and avoid re-entering the prison system. He's spruce, with thick greying hair cut to a medium crew and he's wearing a dark shirt, and smart, tinted reading glasses. Morris speaks confidently, but when he recalls what happened, his voice fades.

"And then I pulled out a knife and stabbed him. He died right there."

Morris graduated to adult prison. He went to San Quentin, Corcoran then Tehachapi, doing solitary confinement in each. But out in the general population there was human contact. A handshake, a conversation, a gaze being met. In August 1991, however, all that changed. Morris was transferred to

ATION

HARA TAKETO/GETTY IMAGES

Pelican Bay, a supermax prison in northern California where the inmates were housed in windowless, poured concrete cells that measured 2.4 x 3.0 metres, around half the size of a standard car parking space.

“When the door is closed, even though it is perforated plate steel, you could feel your soul being sucked out,” he recalls. “You’re standing there naked with what they handed you and you’re just looking at the cell and you realise there is nothing in here but a concrete box, stainless steel sink, a toilet. You’re standing there … barefoot on cold cement, and you’re saying, ‘well, this is it’.”

What Morris didn’t realise was that a sentence to solitary came with hidden extras. Soon, like hundreds of fellow prisoners, he would get high blood pressure. His risk of heart disease would go up. He would get symptoms of anxiety, sleeplessness, and depression. His knees and back would ache and he’d be taking anti-inflammatory medication. But few people cared about the plight of hardened criminals doing time.

Then the pandemic hit, and much of the world was forced into its own brand of lockdown isolation. Rates of depression and anxiety skyrocketed. The American Academy of Paediatrics declared a national emergency in children’s mental health. Now everyone was interested in the very same question: what does isolation do to bodies and minds? Scientists tackling that question have come up with some disturbing answers. Isolation, it seems, changes us down to our core, right down to the level of our genes.

Blue genes?

These days Steve Cole is a professor of medicine at the University of California, Los Angeles, but in the late nineties he was a virologist studying HIV. And he was perplexed. Something odd was happening with a subset of the gay men who were getting the virus. Their immune system was declining faster, and they were dying earlier.

"The ones that were most vulnerable were those who were most socially marginalised, especially the guys who were in the closet," Cole recalls.

"How was it that the HIV genome operated differently in the body of a person who was living in the closet, and constantly afraid of being discovered and losing his job, or his family, or his friends?"

Cole embarked on a series of studies to find out, and unearthed something astonishing. Gay men with a "socially inhibited" temperament were switching on their "fight and flight" sympathetic nervous system. They were pumping out stress hormones, including one called noradrenalin, which binds to a white blood cell that's key in the fight against HIV, the T lymphocyte. Those lymphocytes were then winding back production of proteins called interferons, critical defenders against viruses.

"There was a set of programs that were built into the human immune system, that caused threatened people to throttle back on their antiviral immune responses," says Cole.

Gay men with a "socially inhibited" temperament, it turned out, were switching on the "fight and flight" sympathetic nervous system.

Incredibly, the social truth of sexual orientation was playing out at the level of these men's infection-fighting cells. Cole presented his findings at a thinktank and, afterwards, was approached by a man with an unusual request. His name was John Cacioppo and he was a pioneer in the scientific study of loneliness, whose links to physical diseases such as heart disease, Alzheimer's and high blood pressure were only just being teased out.

Cacioppo wanted to know if the stress of social isolation could do similar things to the immune system and might somehow, be elevating the risk of chronic disease. Cole jumped at the chance to work with him.

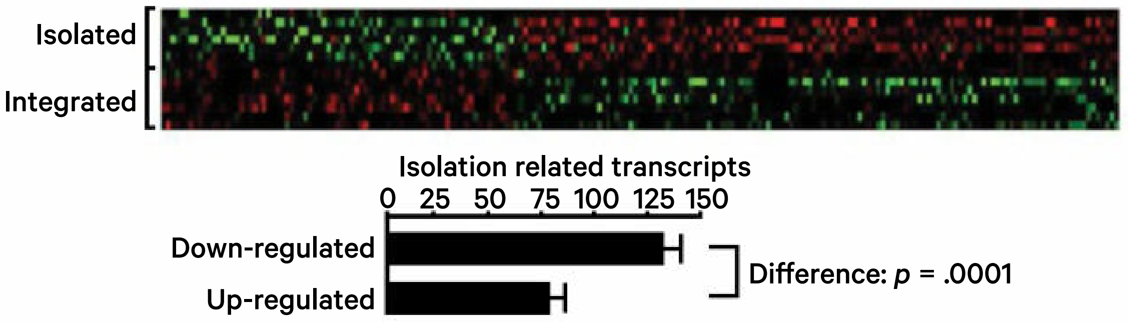
"We did this initial study. It was painfully small, like, 14 people. A really small number of chronically lonely individuals, and another complementarily small number of chronically, socially integrated individuals. And we just took some white blood cells that John had stored in freezers and did this RNA profile on them," Cole remembers.

That profile homed in on the activity of genes in the white blood cells. It was a small study, but the results were emphatic.

"If you look at the genes that were most reduced in activity in lonely people, a surprisingly high proportion of them were the genes that were involved in type one interferon responses, these basic, innate antiviral responses," says Cole.

"That was really stomped down in these lonely people in a way that looked a lot like the gay men in the closet."

CAN LONELINESS BE SEEN IN YOUR DNA?



A study by medical researcher Steve Cole explored the relationship between subjective social isolation (or loneliness) and gene expression in leukocyte cells in a group of chronically lonely and socially integrated people. Analysis identified 209 genes with a greater than 30% difference in average expression levels between the lonely and non-lonely groups. In the lonely group, significantly more genes were downregulated (red) than upregulated (green): 131 to 78.

The stress of loneliness – the subjective, unpleasant experience of social isolation – was doing similar things to the stress of hiding one's sexuality.

DIMITRI OTIS/GETTY IMAGES

The stress of loneliness – the subjective, unpleasant experience of social isolation – was doing similar things to the stress of hiding one's sexuality. Something, however, didn't gel. How could a stunted response to viruses put lonely people at risk of illnesses, such as coronary heart disease, that seemingly had nothing to do with a virus?

Cole's study had picked up a clue. If lonely people were making less interferon, genes linked to production of something else were in overdrive.

Lonely people were churning out more proteins, known as cytokines, that ramp up inflammation. And inflammation is central to heart disease and increasingly thought to play a role in cancer and Alzheimer's, the very diseases Cacioppo was interested in.

"It was pretty clear that there was this teeter totter regulation where the human immune system, which is generally pretty heavy on antiviral capacity and kind of stomps down on inflammation, was recalibrating in the opposite direction in these lonely people," says Cole.

According to Cole there are sound evolutionary reasons the body would do this. Our default mode is to be prepared for the infectious threat we see all the time – socially transmissible viruses. A rarer event is a wound which, if it gets infected with bacteria, can kill us quickly. It is the inflammatory response, and the mobilisation of different types of white cells, such as monocytes, that mop up these bacterial invaders.

The upshot, says Cole, is that we need to be able to pivot, rapidly, from an antiviral to an antibacterial footing, something the stress response achieves well.

"Loneliness is just a surprisingly good way of being threatened. The primary safety signal for most humans is being a member of some kind of supportive community, a family, a tribe." The body, then, sees loneliness as a cue that injury, and bacterial infection, are just one predator away.

When the pandemic began, Cole was a go-to guy for the media, who were desperate to uncover what the science showed about millions of people in enforced isolation. Cole realised he could only make inferences from previous studies. Then he realised he might have the answer right in front of him.

For many years Cole has worked closely with primate researcher John Capitanio, a psychologist at the University of California, Davis. Around 2016 the pair, in a team that included John Cacioppo, began a study of rhesus macaque monkeys at the California National Primate Research Centre. It's a sprawling facility on the outskirts of Sacramento, where scores of monkeys cohabit in half-acre field cages equipped with play gyms, mini-Ferris wheels and tree branches.

The team wanted to catalogue the behaviour of lonely and non-lonely monkeys during two weeks isolation in a smaller cage. When the media queries started pouring in 2020, Cole realised the experiment was a near-perfect model to study the effects of lockdown. So the team switched tack. What would the mere fact of being separated from its friends do to the monkey's immune system, they wondered? A lot, as it happened.

The results, published in *Proceedings of the National Academy of Sciences* in 2021, found the monkeys dialled up, by around 9%, production of white blood cells, called classical monocytes, responsible for inflammation. Cells that make interferon and fight viruses, such as lymphocytes, plummeted by up to 50%. How soon did it all start? Within 48 hours of the animals entering the cage. It was a dramatic demonstration of the biological force of isolation.

Not everyone, of course, experiences lockdown alone. Parents, for example, have to care for children. The researchers knew older primates are predisposed to care for juveniles, so they tried something else. A month after each monkey was released they put it back into isolation, this time caged with a young monkey.

"That made a huge difference in terms of how the adult monkey's biology responded to lockdown," says Cole. "The monkey that goes into the same setting, with an infant there, doesn't show any material ramp up in inflammatory cell, monocyte production, and doesn't show any material ramp down in antiviral biology."

Put a monkey in lockdown with caregiving, they had found, and all those stress-related changes in immunity seem to melt away. The reason why the mere presence of a needy child could taper the adult monkey's stress response may well come from a curious study that Cole and colleagues published in 2013.

They analysed gene expression in the white blood cells of 80 healthy adults and, at the same time, asked them how, on balance, their lives were going. Some people scored higher on scales that measure a sense of purpose and meaning in life, so-called "eudaimonic" well-being (in the writings of Aristotle eudaimonia refers to "human flourishing"). Those people, the team found, were turning down the threat-related immune response.

Cole has since gathered evidence that being connected to a deeper purpose activates brain areas linked to motivation and "wanting", including the ventral striatum and nucleus accumbens. Those areas can quell the effects of the brain's anxiety centre, the amygdala, whose job is to put the body on a threat footing.

"When those monkeys engage in caregiving, and when humans engage in this kind of virtuous and striving and generative activity, what you're getting is a lot of activity in this seeking, hoping, wanting section of your brain that essentially vetoes some degree of threat-related biology," says Cole.

It is a facility, Cole believes, that likely arose to push parents to face danger for the sake of their children. If a parent is to run inside a burning building and save a child, for example, they must put the risk of self-harm to one side.

Closing time

No animal study maps perfectly onto the human condition. But it's hard to avoid speculating that aches in Jack Morris's back and knees were manifesting a change in his inflammatory biology.

Inflammation has also been linked to high blood

But something else was happening too. The hunger for human contact, so familiar to people who've spent time alone, was ebbing away.

MARTIN BARRAUD/GETTY IMAGES

REMOTE CONTROL: THE ZOOM EFFECT

Dr Louise Hawkley is a principal research scientist at NORC at the University of Chicago and has studied loneliness for more than two decades. When the pandemic hit, Hawkley was on a team that had been surveying a group of older adults as part of the National Social Life, Health, and Aging Project.

“There was all this hype around video calls,” says Hawkley. “That’s your answer, you better learn how to do video calls because then you’re going to get your best quality interaction with other people.”

Hawkley convened a new team to survey around 2500 people from the cohort, all aged 55 and up. They asked respondents to rate their levels of happiness, depression and loneliness, which could be compared with ratings from the same group taken in 2015, pre-pandemic. People also reported their level of contact with family and friends, how much was in-person, how much was via video and phone calls, email and messaging, and how it all tracked over the pandemic. Hawkley’s findings, published in the *Journal of the American Geriatrics Society* in 2021, showed that around 40% of people had reduced in-person contact.

The effects, too, are unsurprising. “The more you stayed at home and didn’t have contact, the more lonely you became, the more depressed symptoms you had, the less happy you were,” says Hawkley.

Most worrying, though, was the impact of remote contact. “Could they improve that by having more virtual interactions? The take-home seems to be ‘no’,” she says. Hawkley’s team found that between 16% and 26% of respondents increased their levels of remote contact during the pandemic.

“It seemed to make no difference,” says Hawkley. “It did not alleviate loneliness to any significant degree. It did not alleviate depressive symptoms or improve happiness.”

There is little data why this is the case, so Hawkley can only offer her intuition, albeit drawn from decades of research.

“It’s the whole sensory experience. It’s not just what we see and hear but all the subtle cues we get from, call it body odour, pheromones, whatever. … And there are subtleties in body posture, physiognomy, that essentially change with emotions. That is very hard to detect accurately on a virtual platform.

“We all have that need for assurance, for security, and we don’t give it to babies by having them watch a screen. It requires this very immediate detection of signals, eye to eye, hand to hand, chest to chest, just to round us out as what we are as people. Because we aren’t islands. We are not sufficient for ourselves.”

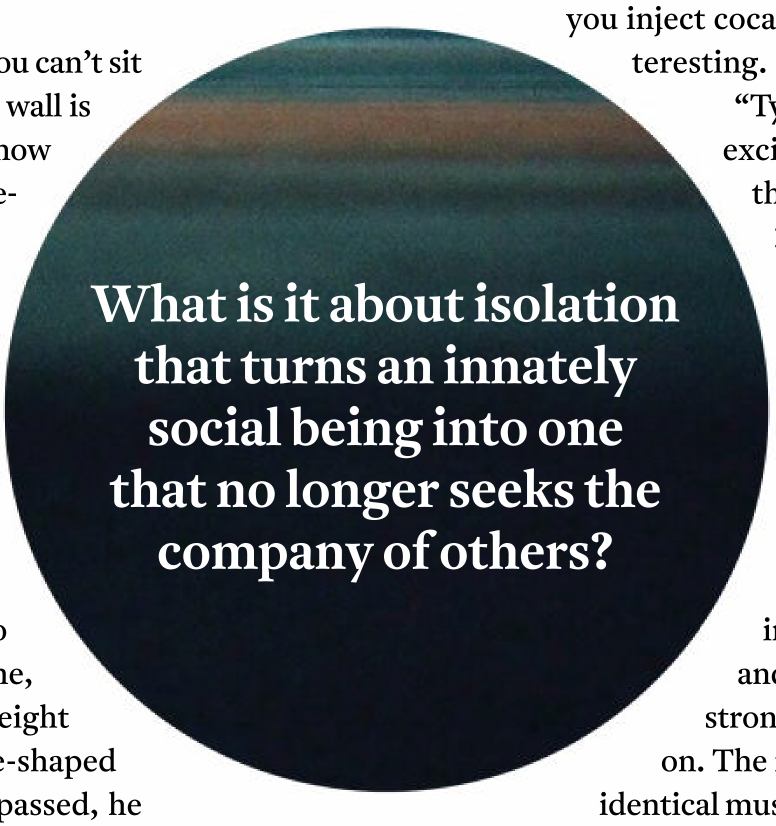
pressure, but it’s likely the stress of isolation, and a rise in stress hormones like cortisol, contributed too.

Morris also seemed driven to find a higher purpose. He studied maths. He took legal training and helped fellow inmates lodge writs. He read thousands of books on everything from quantum physics to the migration patterns of the peregrine falcon.

“You have to figure out a way to exist. You can’t sit there and stare at the wall because then the wall is going to start moving on you. I didn’t know how to draw. I learned it, because it gave me something to do eight to ten hours of that day.”

There were pencils, but no colour. Morris drew a bird, with intricate feathers and strange, cord-like appendages in red, blue and green. He made the colours from Skittles and M&M’s. Somehow, in that prison within a prison, Morris was impelled to find meaning. But something else was happening too. The hunger for human contact, so familiar to people who’ve spent time alone, was ebbing away. Morris could yell to the eight other people in his “pod” through the dime-shaped holes in the steel door. But, as the years passed, he stopped.

“You don’t even want to communicate no more. Your world becomes smaller and smaller and smaller. Somebody calls up to you saying, ‘what are you doing? I haven’t heard from you in two days.’ And we’re in the same pod. And my cell is next door to him.”



What is it about isolation that turns an innately social being into one that no longer seeks the company of others?

In pursuit of happiness

A bit over a decade ago Gillian Matthews was elbow deep in her PhD at Imperial College London. She was researching addiction, specifically, the effects of cocaine on an enigmatic structure in the mouse brain called the dorsal raphe nucleus or DRN. But when you inject cocaine into mice things can get, well, interesting.

“Typically the mouse on cocaine is quite excitable,” says Matthews. “You’ll put them in a separate cage overnight for 24 hours, so that they don’t interrupt their cage mates.”

Matthews had a control group of mice getting salt water injections so, to keep conditions equal, they were also isolated for 24 hours. When Matthews examined the mice brains afterwards she found a major change in the cocaine group – connections in neurons that feed into the DRN, and drive its activity, had grown way stronger. But something weird was going on. The mice that got salt water had an almost identical muscling up of those same neurons.

“My initial reaction was that I’d probably mixed up the syringes, given the saline mice the cocaine,” Matthews remembers. She repeated the experiment. Same result. The effect was real. The simple fact of isolation looked to be pumping up neurons that drive activity in the DRN. But why?

Until now, Matthews had been recording DRN activity in brain slices from euthanised mice, whose neurons can remain active for 12–14 hours. To get a better handle on the DRN meant studying live mice using different techniques. So, in 2013, Matthews crossed the Atlantic to take up a post-doc role in the lab of Professor Kay Tye, then at MIT.

They began experiments in animals bred so that fluorescent indicators could track the influx of calcium into their neurons, which happens when the neurons are firing. It's called calcium imaging – brighter neurons mean more activity. For 24 hours the mice were either held in isolation or caged with a bunch of other mice. When the time was up they had each mouse say hi to an unfamiliar young mouse.

The mice that had been group-housed had a bit more activity in the DRN neurons. But in the mice that had done solo time, it was something else again.

"These neurons go crazy," said Tye, shortly after the experiment's publication in 2016.

> "The primary safety signal for most humans is being a member of some kind of supportive community, a family, a tribe." The body, then, sees loneliness as a cue that injury, and bacterial infection, are just one predator away.

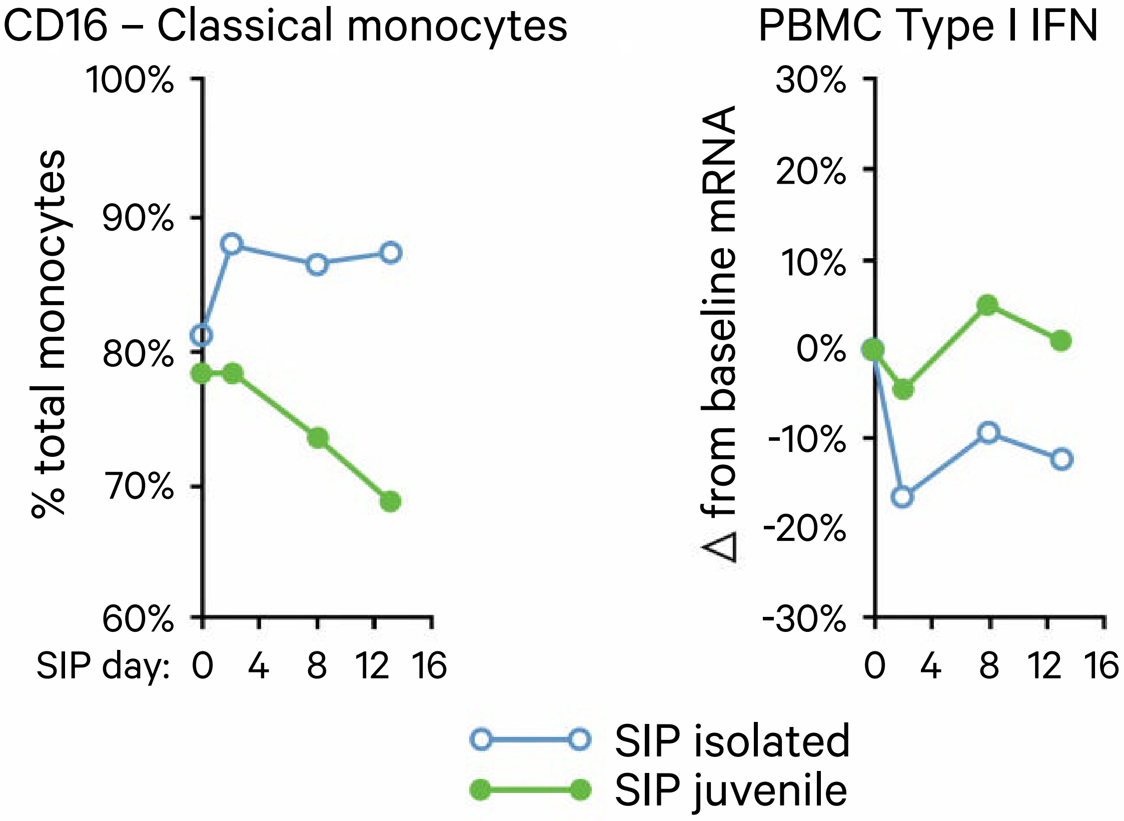
DRN neurons looked to be tracking the social state of the mouse, firing up in isolated animals when they finally reconnected with others. But could those brain cells be doing even more? Were they actually driving behaviour? To find out Matthews and Tye turned to optogenetics, a technique that introduces light-sensitive proteins into neurons, which can then be activated by a given wavelength of light. The team engineered things so the DRN could, effectively, be turned on at the flick of a switch. They put the mouse in a cage with a mesh wall at one end, behind which another mouse was going about its business. And flicked the DRN switch. The effect was immediate, and dramatic.

"We found that they increased the amount of time that they wanted to spend with another mouse," says Matthews. "They increased their social preference, so they spent more time on that social side of the chamber." It was a stunning finding. The DRN was, almost single-handedly, deciding whether mice would be shrinking violets, or party animals.

Matthews had another tool at her disposal. Optogenetics can also silence neurons. When mice go into isolation for short periods they get convivial on release, as if to make up for the social deficit. The team put mice into lockdown for 24 hours, and then used optogenetics to turn off the DRN neurons. "When we silenced these neurons after animals had gone through 24 hours of isolation, we found that it suppressed that rebound social contact," says Matthews.

The DRN, they had discovered, was crucial to the process of reconnecting after brief isolation. Matthews, Tye and other researchers at the Salk

MONKEY BUSINESS



In 2020, Cole tested the health effects of social isolation in a group of macaque monkeys, who spent 14 days isolated in smaller cages (blue), and, later, 14 days isolated in a space with a juvenile macaque (green). Changes in the immune system, such as an increase in inflammation-related classical monocytes (A) and downregulation of the type I interferon response (B), were significantly reversed in monkeys when they were paired with a juvenile.

Institute in California, where Tye is now based, have set out what they think happens over longer periods of isolation when many people become socially withdrawn.

In two key papers, published in 2019 and 2021, they describe the DRN as part of a system that works like a thermostat. Reduce your contacts and the system will prompt you to mingle and get your social "temperature" back to the set point. Matthews and Tye call this "social homeostasis".

But deprive someone of social contact for months on end and they can get antisocial, content with the new normal of fewer entanglements. Matthews and Tye think this is a "set point adaptation", a reset of the thermostat that winds down our social needs. You might feel fine in the trackie-daks and slippers of lockdown, but emerge into your former social milieu and things get uncomfortable. It now feels overcrowded and people can react with avoidance, aggression or social anxiety. So, what should people do to keep things steady in lockdown, and to re-adapt when they come out?

In lockdown with caregiving, they had found, all those stress-related changes in immunity seem to melt away.

KOHEI HARA/GETTY IMAGES

Hearts and minds

In December 2016 Jack Morris was told, after 30 years of continuous solitary confinement, that he would be transferred to general population in a prison downstate.

"I spent Christmas staring out of a window. Out of a window. And I saw snowflakes falling from the sky and that's after living in a cell for decades and not seeing no night sky, or no sun, or no clouds," he says. "For weeks I had headaches. I was seeing colours. I'd see the colour of dirt. I'd see the colour of grass. Because in there it's strictly concrete, you don't see colour. You walk on concrete, you sleep on concrete, you eat on concrete. You stare at concrete."

Re-connecting with people came with a distinct set of challenges. "I didn't know how to socialise. How can I go up to somebody and talk to them? What am I going to do, look at 'em and talk to 'em? Shake a hand? You don't do that. That's foreign to you. It's no longer something you know about. It's something you have to learn all over again."

The process wasn't helped by the profound anxiety Morris felt being around people again. "Your heart, you could literally hear it pounding in your chest. Somebody would just run by. You're turning around, you're jumpy, you're jittery. You can't sit down. You can't get any relaxation."

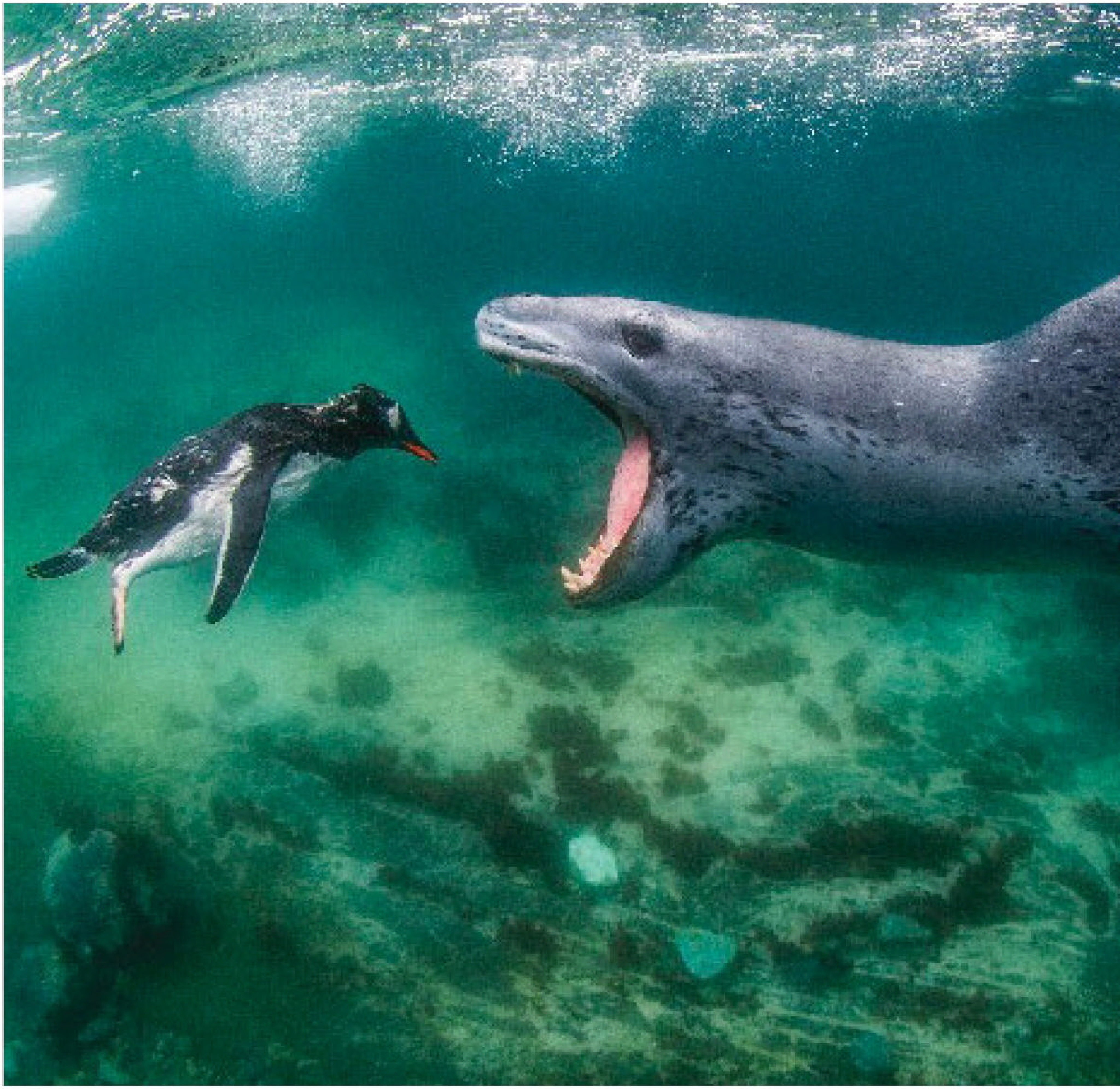
Released from prison in 2017, Morris has slowly inched his way back into society. Millions of people around the world are recovering from their own, less extreme struggles with isolation.

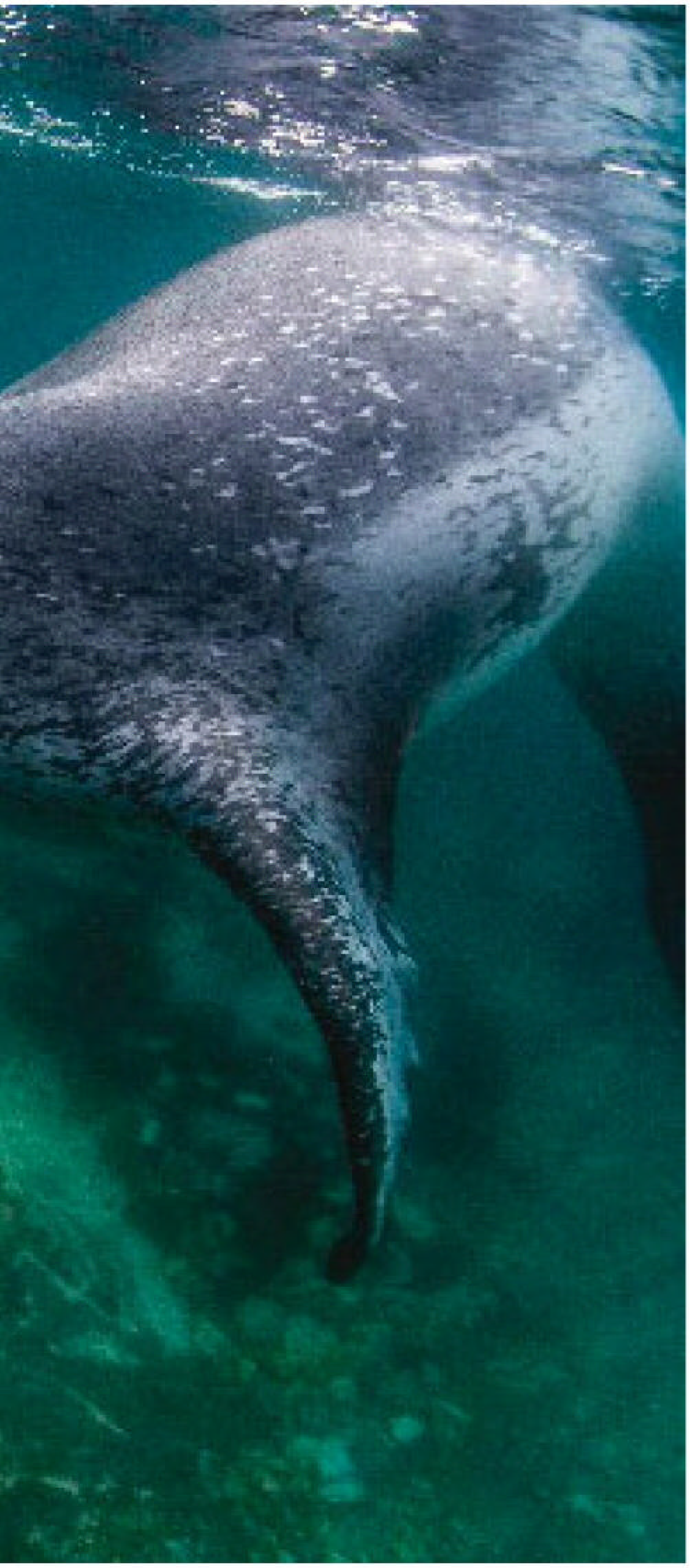
"You do need to be conscious that there are long term changes that could have impacted how long it will take people to change their behaviour and to feel comfortable and to feel less anxious," says Matthews.

But deep in all that neuroscience there is also a message of hope. "If we have learnt anything about the brain it is that it's really good at adapting. I think people will adapt back, and I think the brain will adapt too." ◉

PAUL BIEGLER is a bio-ethicist based in Melbourne. His last story for the magazine, on mindsharing, was in Issue 91.

Wildlife, wild and free

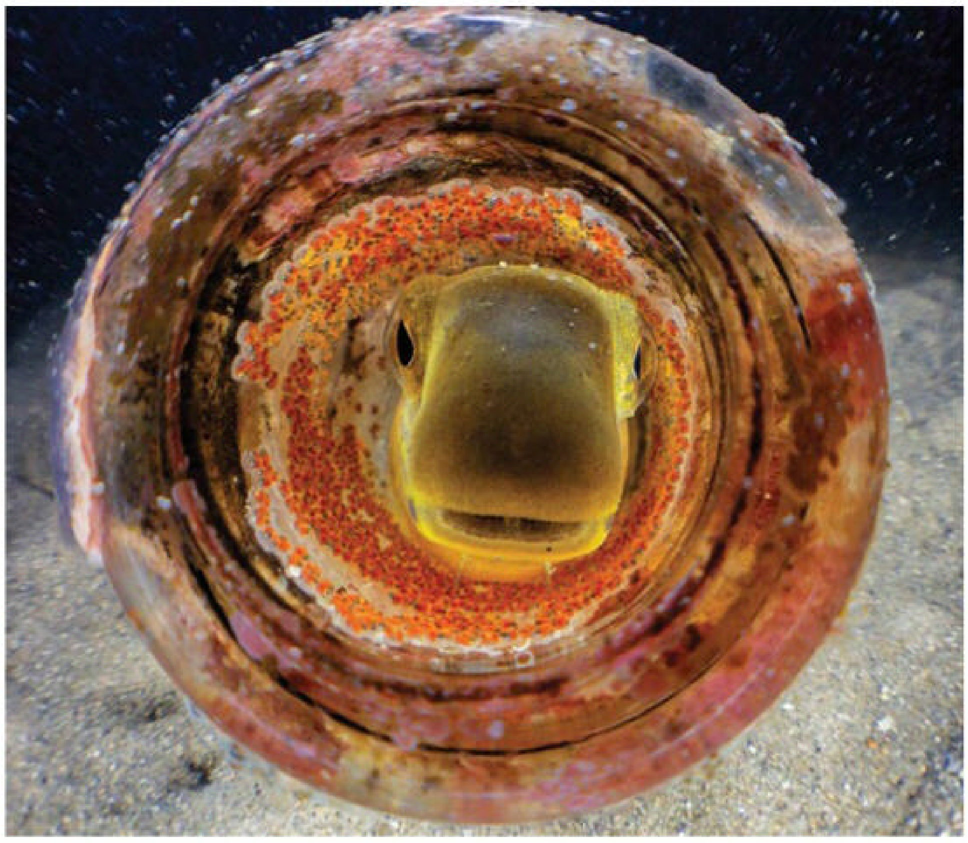




Deadly dive (left): Amos Nachoum waited for low tide for a leopard seal (*Hydrurga leptonyx*) to enter an island lagoon near the Antarctic Peninsula. Nachoum says, "It put its head in the water and looked just like a rock sitting in the receding water." Eventually one of its prey, a young gentoo penguin (*Pygoscelis papua*), swam too close, and the leopard seal caught it and took it to deeper water. "Once the seal reached open water, I followed it and swam parallel to it, observing its actions." Twice the seal let go of the penguin then chased it, as if enjoying the game. But soon, Nachoum says, the end came. This striking image was named gold in the Behaviour – Mammals category, and was overall grand prize winner. *Photographer: Amos Nachoum (USA)*

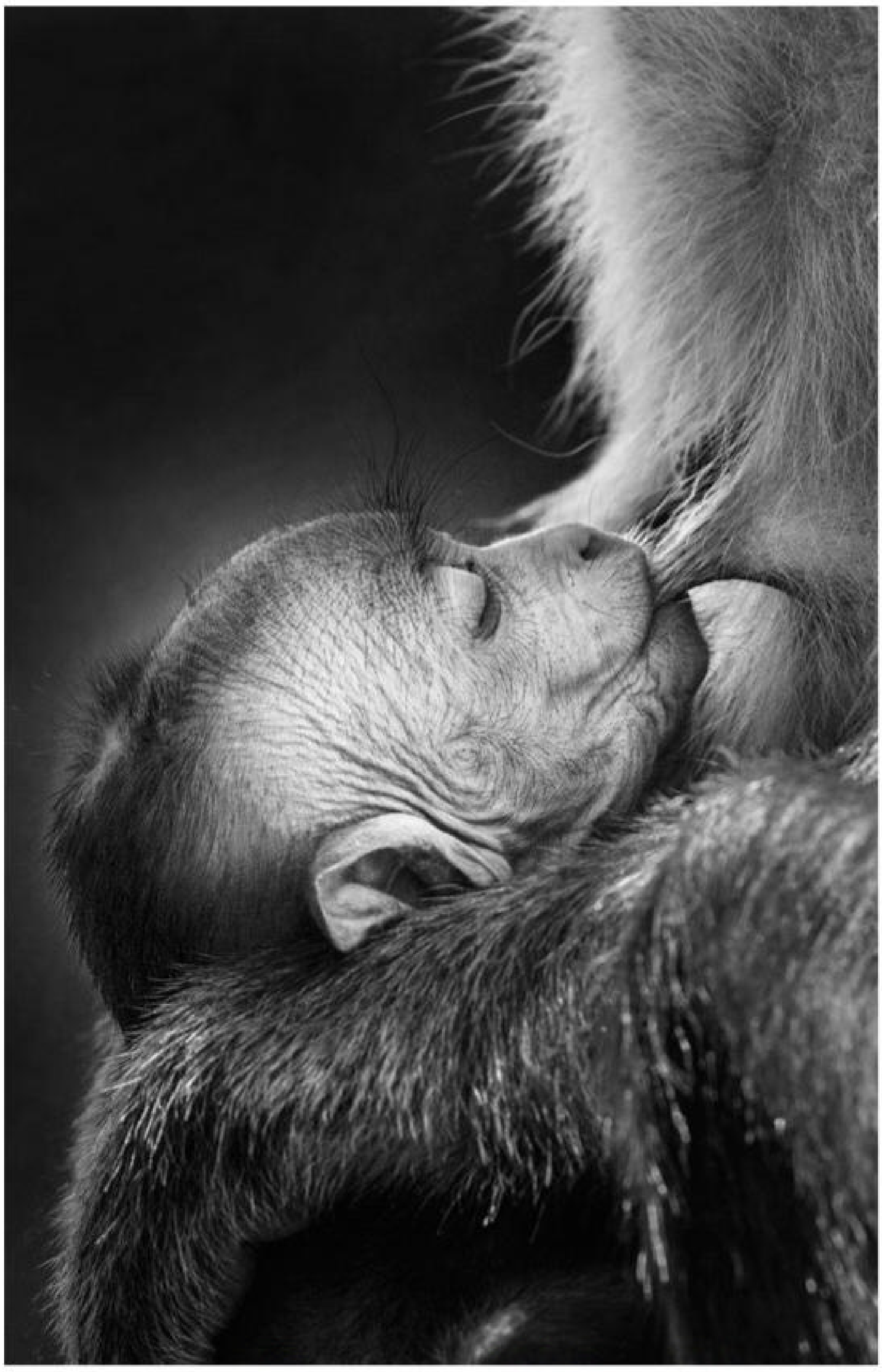
City lights, desert fox (above): The Arabian red fox (*Vulpes vulpes arabica*) is a sub-species of the red fox native to the Arabian Peninsula. They're comfortable in a variety of habitats, including – like many fox species – urban areas. This individual was part of a family that denned close to the city of Kuwait. Awarded silver in the Urban Wildlife category. *Mohammad Murad (Kuwait)*

The World Nature Photography Awards run on a simple philosophy: "Whilst we know that the challenges around climate change are enormous," proclaim its organisers, "amazing things can be achieved if we all come together to affect change." Visit **www.worldnaturephotographyawards.com** to see more winners and learn about entering this year's awards.



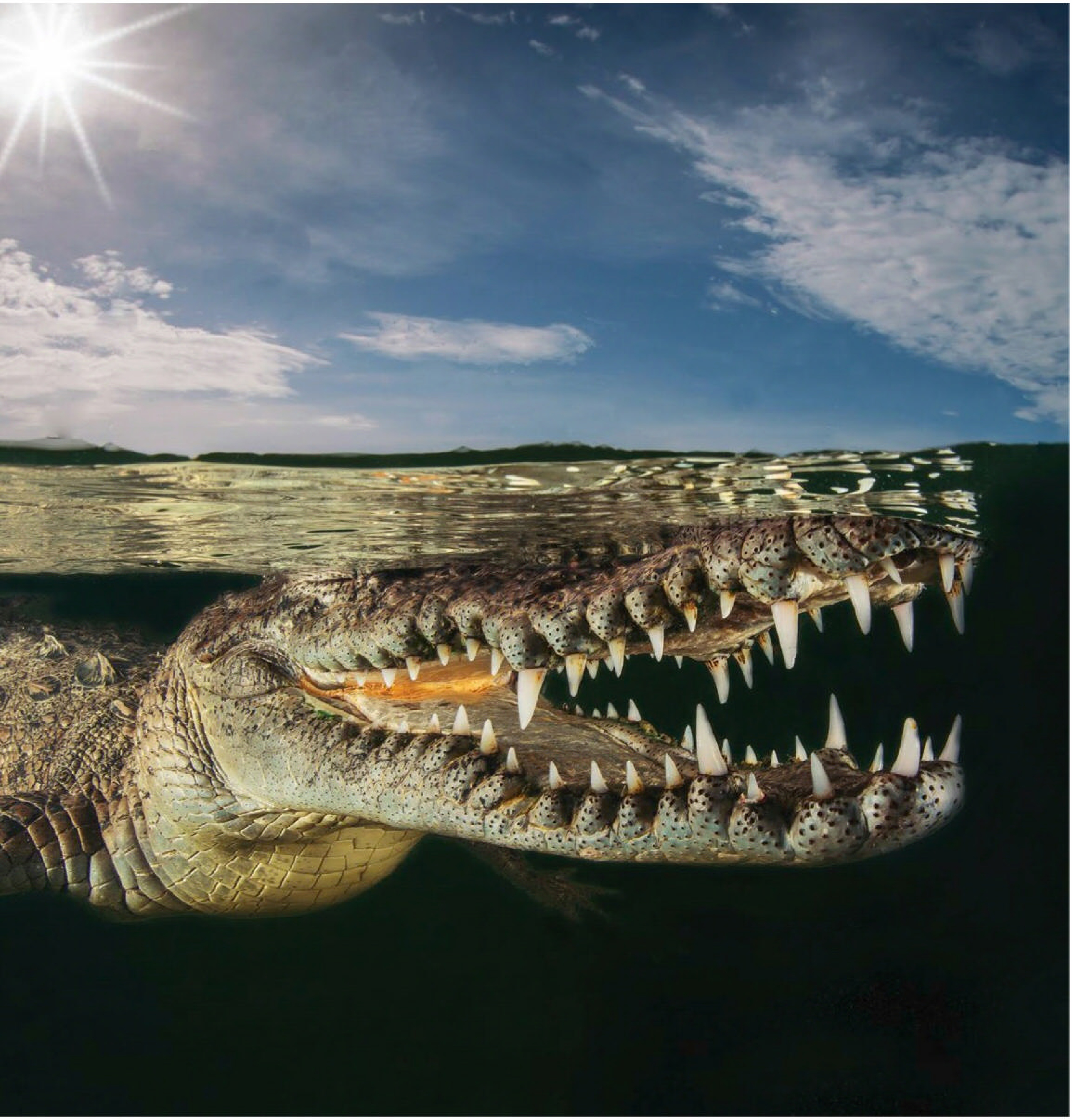
Bottle babies (above): A discarded beer bottle in Chowder Bay, near the Sydney Harbour heads, finds a new use – as the nest of a blenny (*Parablennius* sp.). Awarded bronze in the People and Nature category.

Gaetano Gargiulo (Australia)



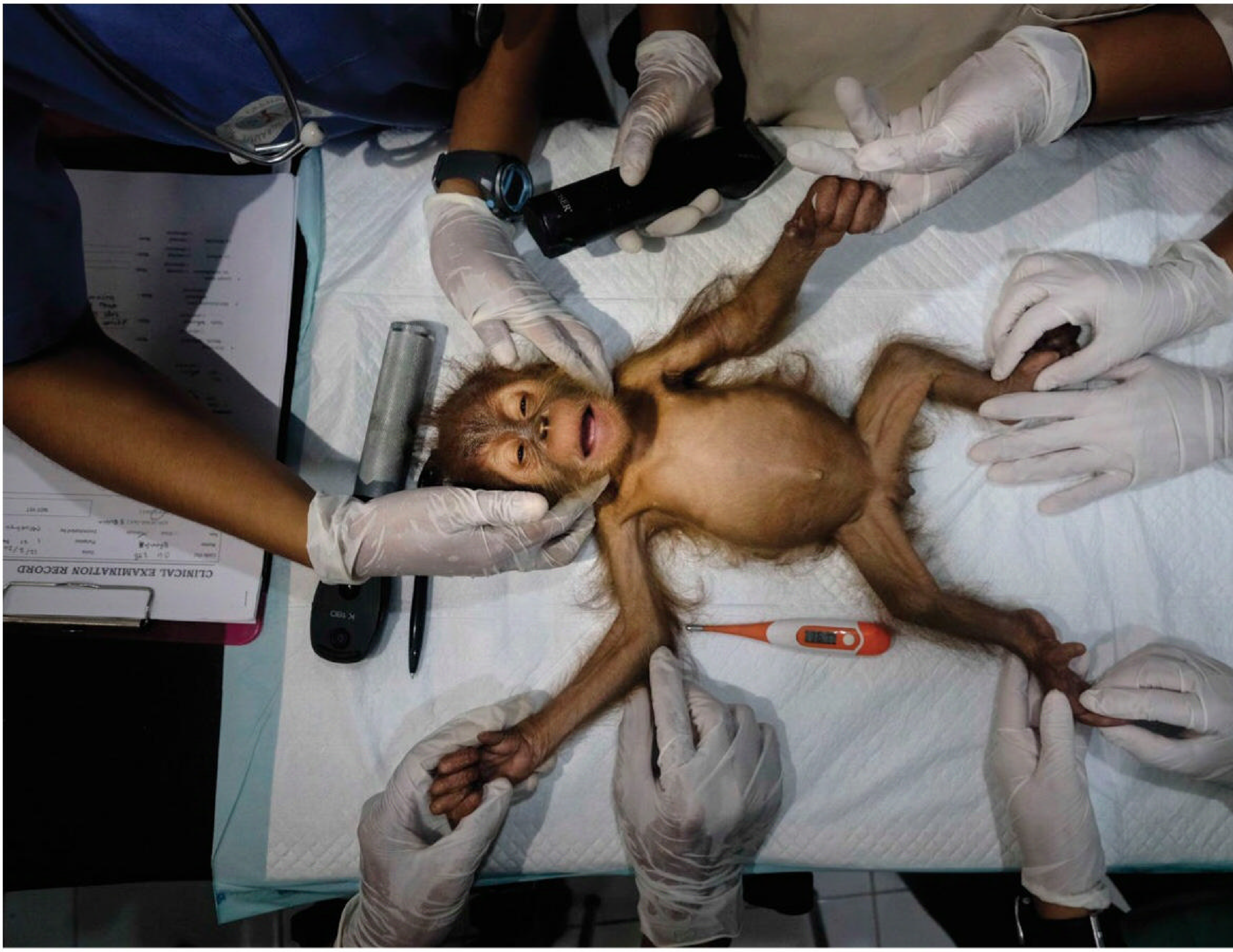
Nursing mother (left): A baby toque macaque (*Macaca sinica*) is breast-fed in Yala National Park, in south-east Sri Lanka. Endemic to Sri Lanka, the toque is one of 44 mammal species protected in Yala; others include elephants, sloth bears, jackals, sambar and spotted deer, and famously leopards – Yala claims to have the world's biggest concentration of the widely distributed big cat. Awarded silver in the Black and White category.

Avanka Fernando (Sri Lanka)



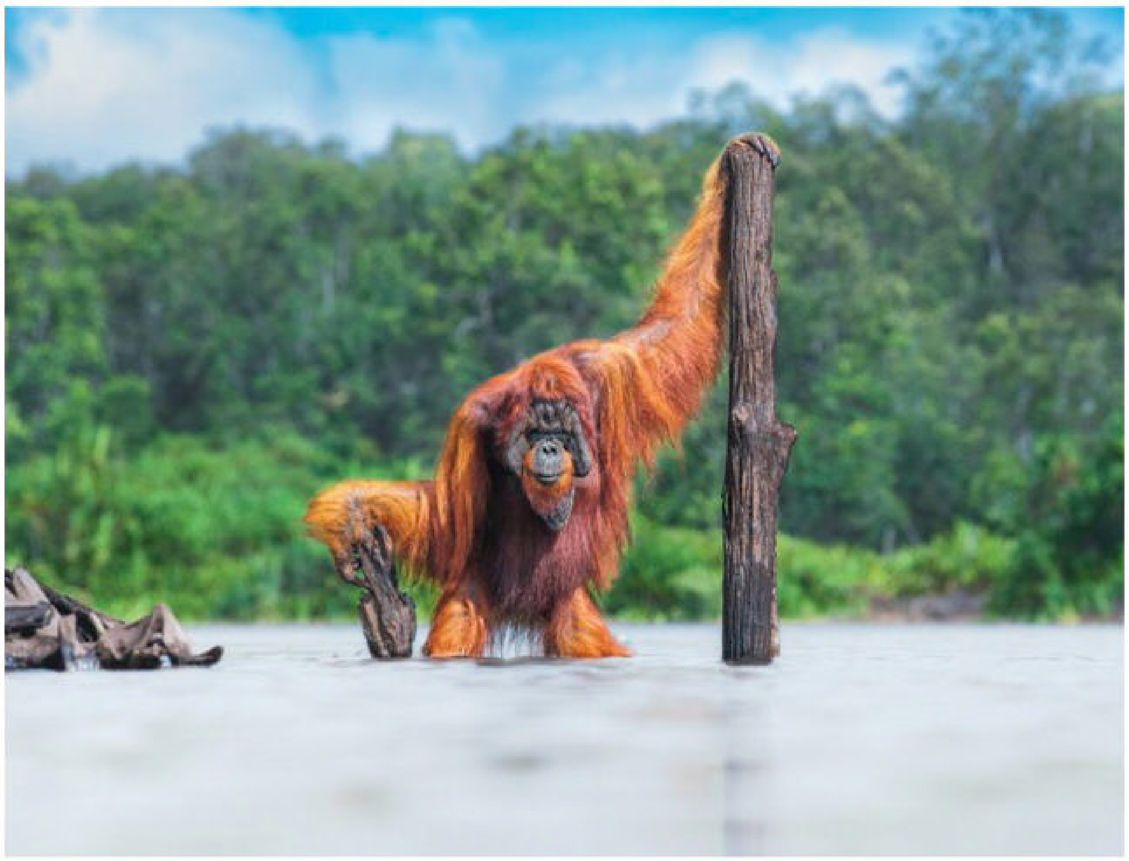
Cuban croc (above): An American crocodile (*Crocodylus acutus*) floats, jaws slack, in waters near the Jardines de la Reina (Gardens of the Queen) archipelago, off Cuba's south coast and one of the country's premier scuba-diving destinations. Male American crocs are typically 3–4m in length and weigh up to 400kg. Fortunately, the species is known to be shy and to avoid humans if possible; attacks are rare, and more rarely fatal. Awarded silver in the Behaviour – Amphibians and Reptiles category.

Massimo Giorgetta (Italy)



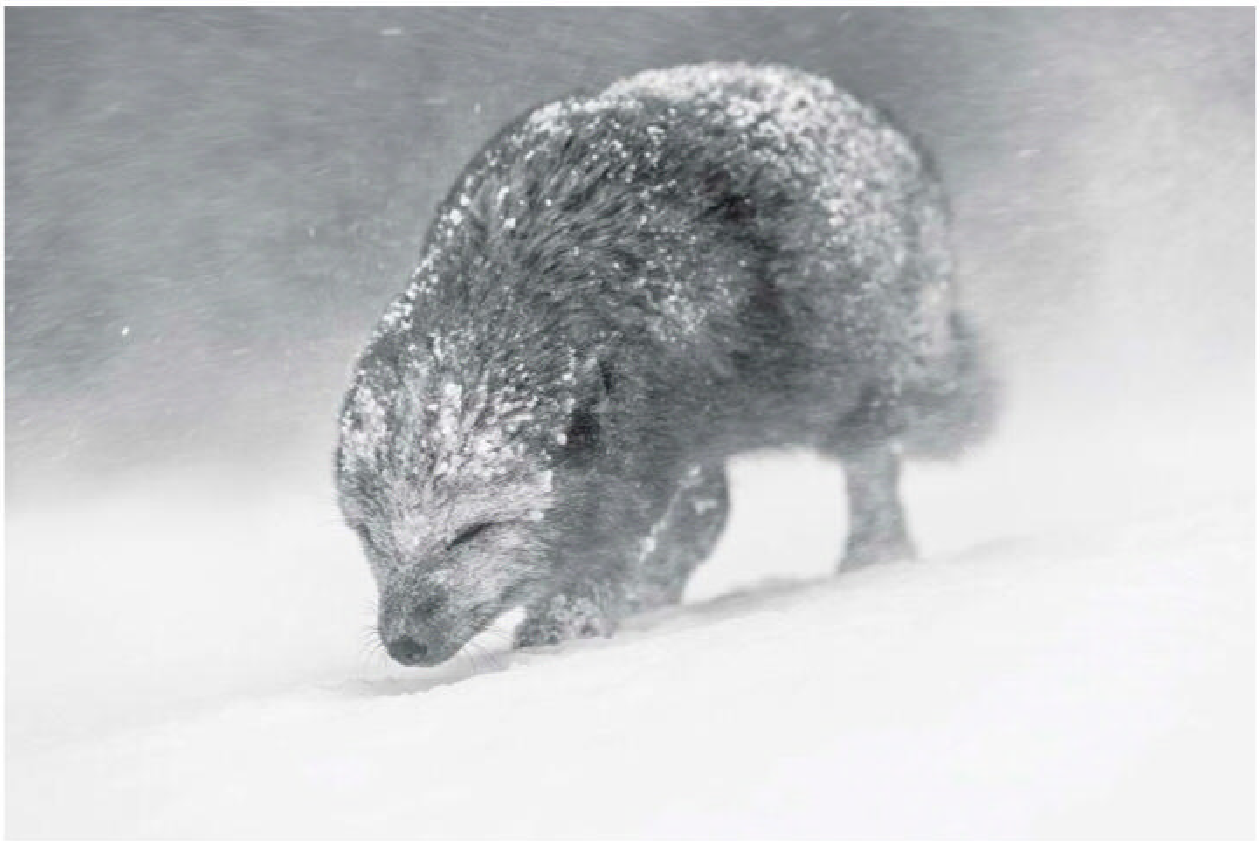
Priceless patient (above): At Sibolangit, the Sumatran Orangutan Conservation Programme's Quarantine Centre, three-month-old Sumatran orangutan (*Pongo abelii*) female Brenda is readied for surgery to repair her damaged humerus. Swiss orthopaedic surgeon Andreas Messikommer took three hours to place a pin and screws to secure the damaged limb. Awarded gold in the Nature Photojournalism category.

Alain Schroeder (Belgium)



Jungle lord (left): Thomas Vijayan encountered this statuesque mature male Bornean orangutan (*Pongo pygmaeus*) mid-river; this spontaneous portrait perfectly captures the solitary ape's flappy cheek-pads, known as flanges, and distinctive throat sac. Awarded gold in the Animals in their Habitat category.

Thomas Vijayan (Canada)

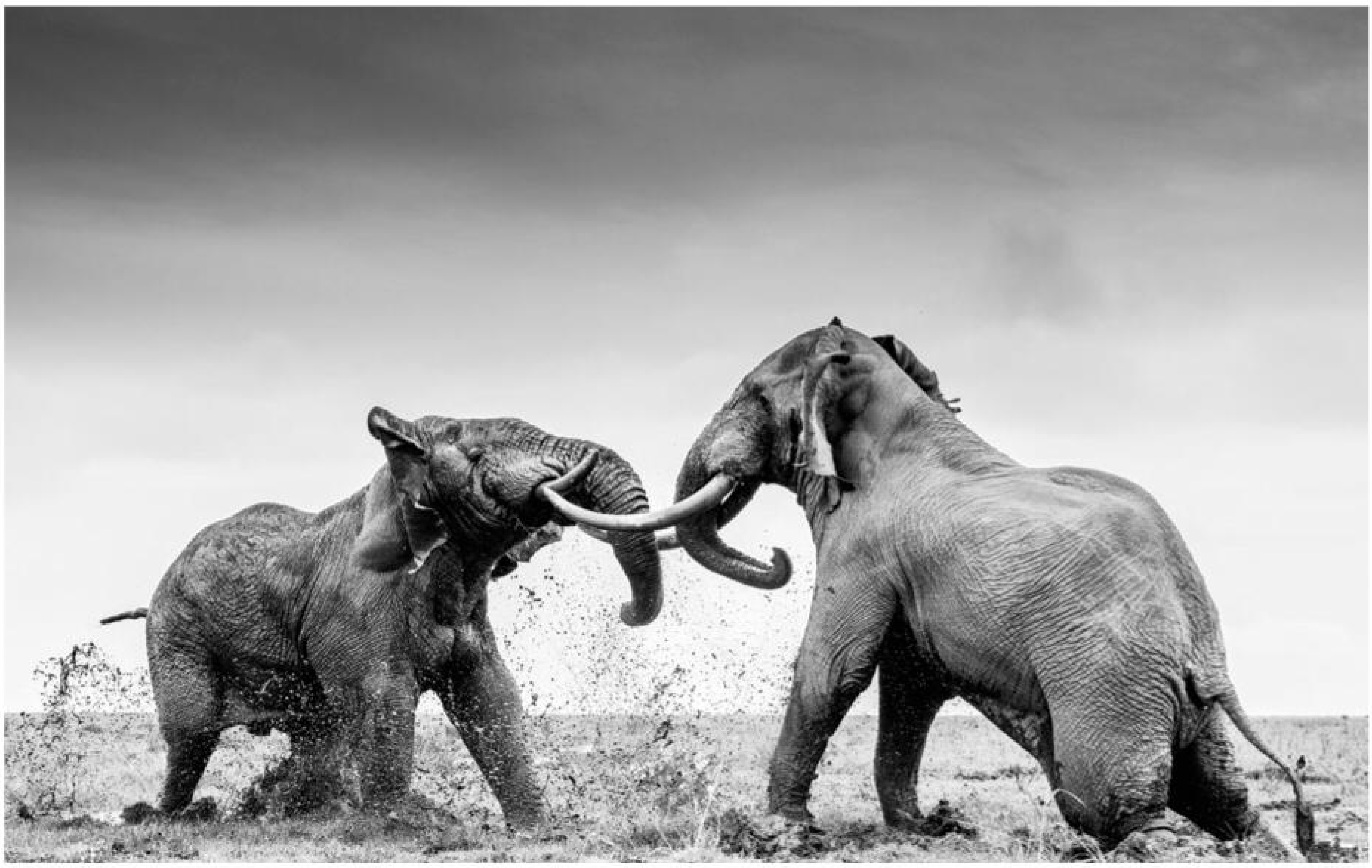


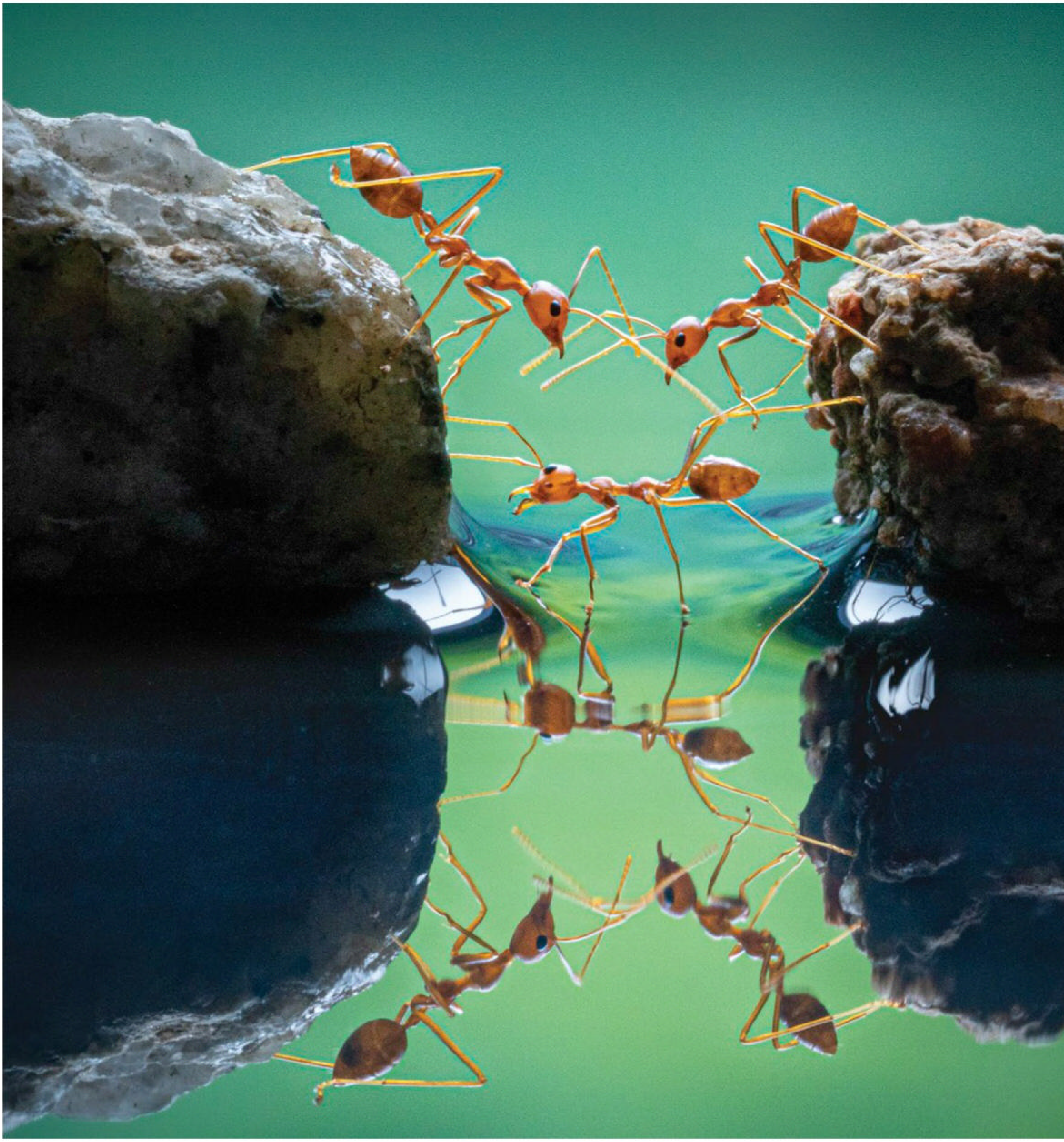
Chilly day out (above): Vince Burton captured this rare blue morph Icelandic fox (*Vulpes lagopus fuliginosus*) on a trip to the isolated Nordic island. Blue morphs don't grow a white winter coat like most Arctic foxes; their fur shows various shades of blue-grey across the seasons. Awarded gold in the Black and White category.

Vince Burton (UK)

Heavy encounter (below): A pair of bull African bush elephants (*Loxodonta africana*) battle for supremacy in Amboseli National Park, Kenya. The 392 sq km park – famous for its views of 5,895m Mt Kilimanjaro, in neighbouring Tanzania – has about 1500 resident elephants. Awarded silver in the Behaviour – Mammals category.

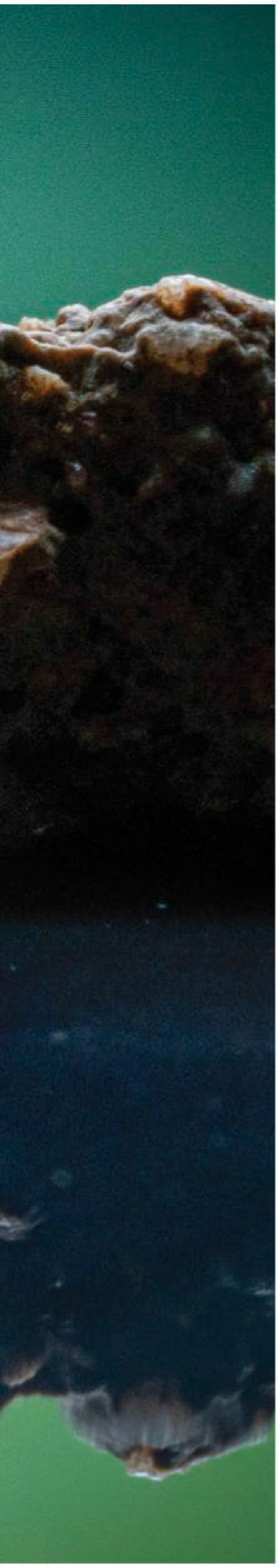
William Fortescue (UK)

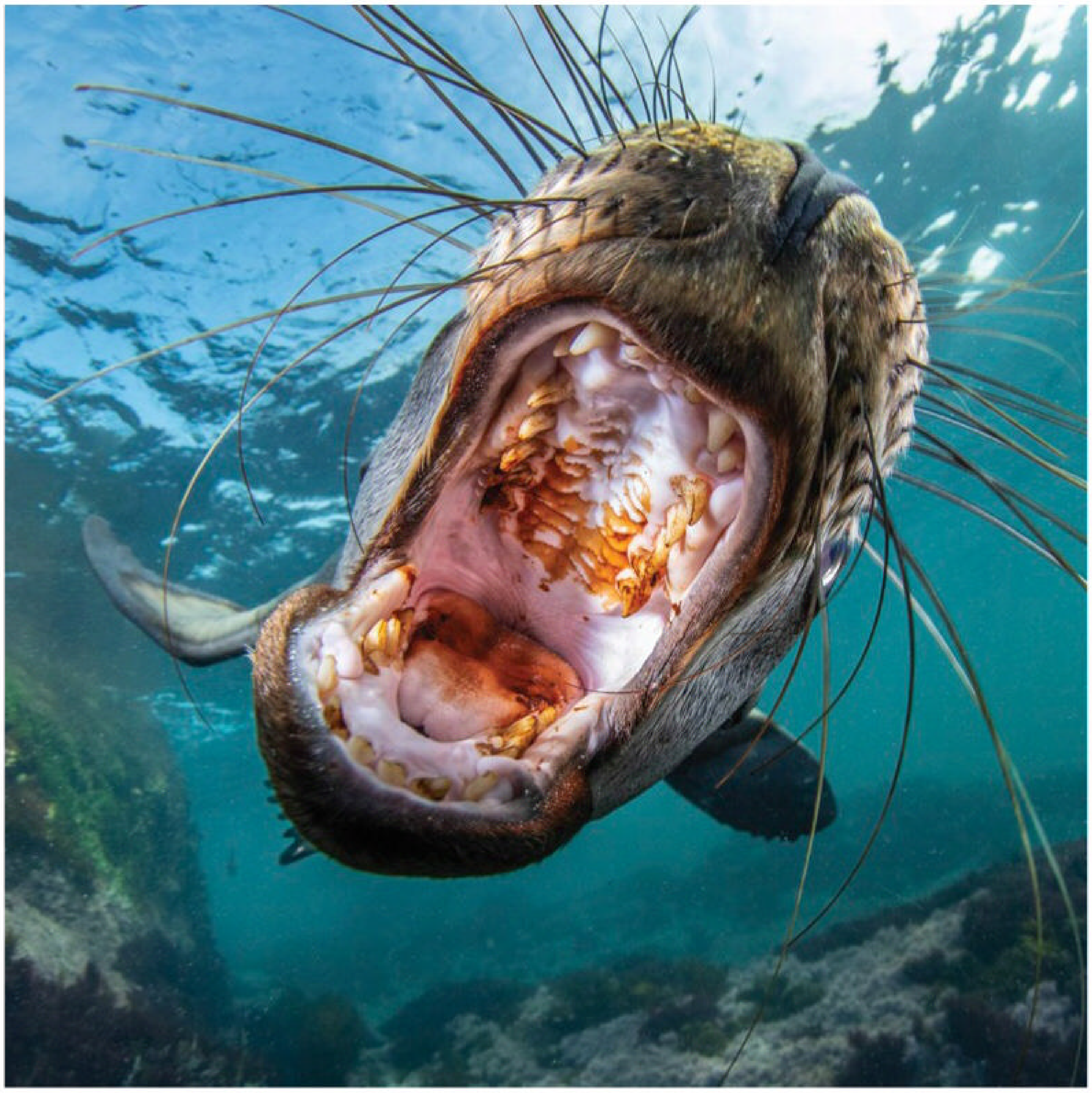




Crossing the breach (above): When scouts at the front of a group of common red ants (*Myrmica rubra*) encounter an obstacle like water, they intuitively form an "ant-bridge" with their bodies, so that their ant-mates at the back of the party can cross. Awarded gold in the Behaviour – Invertebrates category.

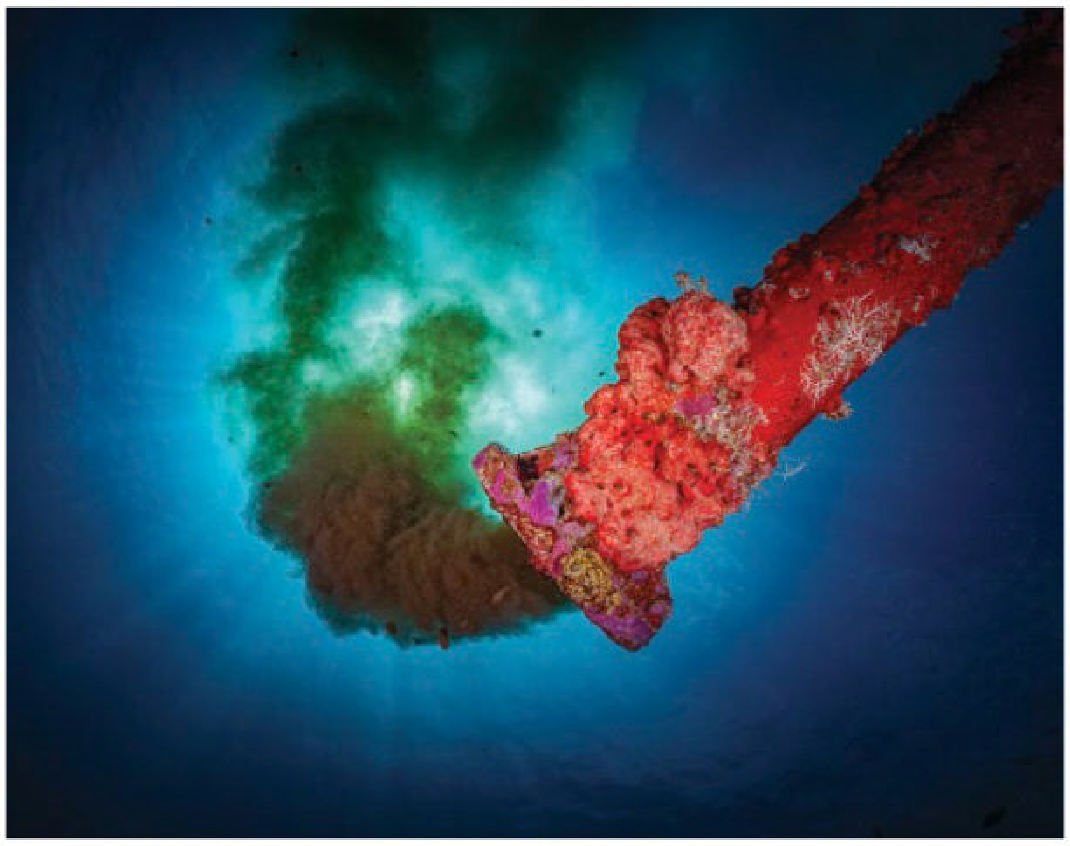
Chin Leong Teo (Singapore)





Open wide (above): California sea lions (*Zalophus californianus*) like to feed on squid and fish – and the occasional clam. The US Navy has trained the intelligent creatures to recover equipment from the sea floor. This juvenile was photographed off the coast of Baja California, Mexico. Awarded silver in the Animals in their Habitat category.

Celia Kujala (US)



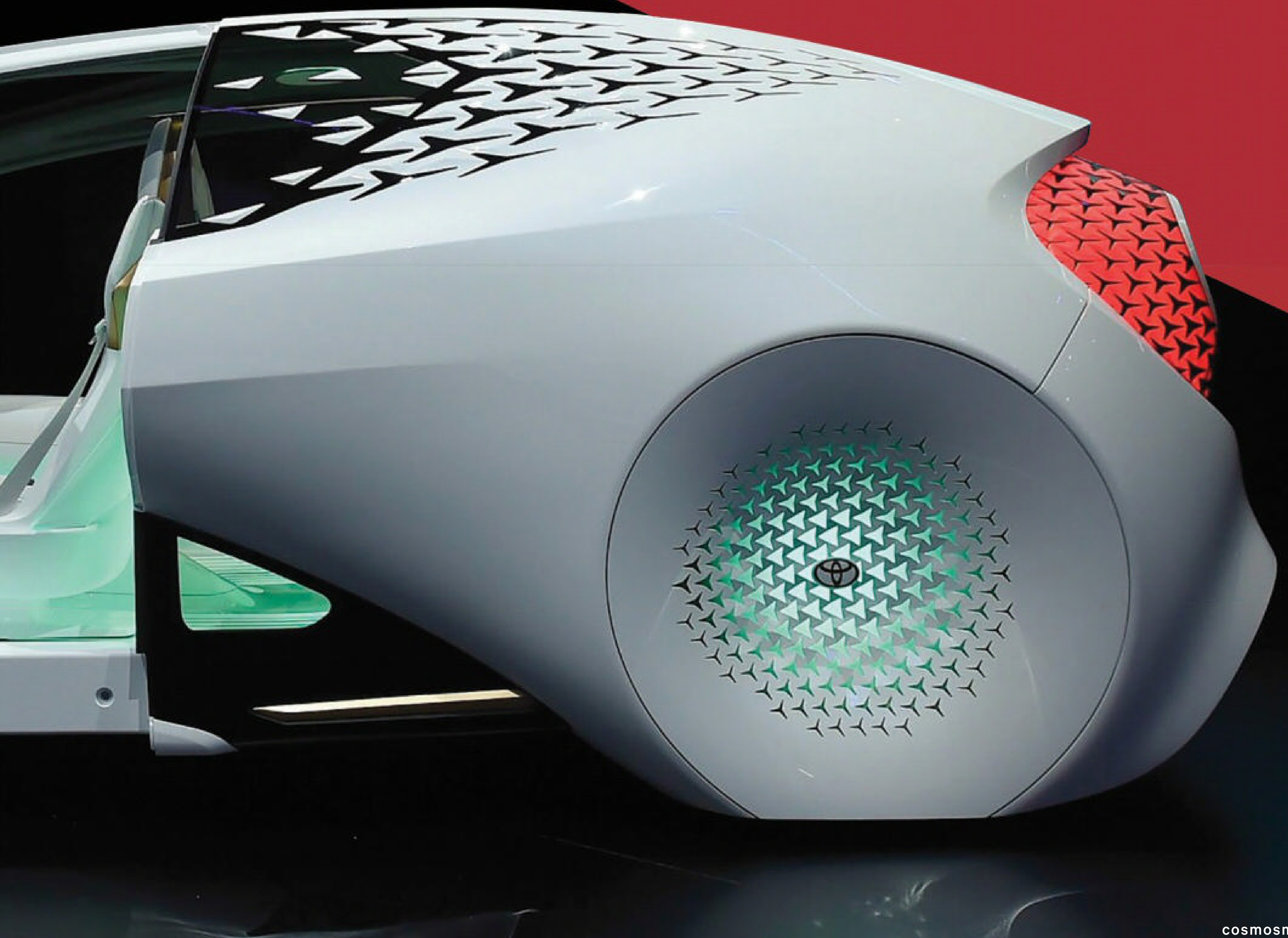
Out of sight, out of mind? (right): This otherworldly thing is not an animal or a marine plant – it's a sewage pipe, from a hotel in the Maldives. Photographer Alexej Sachov believes that "when humans would start to love both worlds above and underwater, there would be still a chance of preventing more environmental pollution". Awarded silver in the Nature Photojournalism category.

Alexej Sachov (Ukraine)

DAVID BECKER/GETTY IMAGES

AND AUTONOMY

Would you give your car a licence to drive? **TOBY WALSH** considers the cases for and against autonomous ehicles.



I begin with what is perhaps the only property that makes AI special. This is autonomy. We're giving machines the ability to act in our world somewhat independently. And these actions can have an impact on humans. Not surprisingly, autonomy raises a whole host of interesting ethical challenges.

New technologies often introduce ethical challenges. And you could argue that autonomy is the one new ethical challenge that AI poses. All the other challenges – such as bias or invasion of our privacy – are ones we have faced before. For example, we have been trying to tackle racial bias for decades. AI may have put the problem on steroids, but it's an old problem. Similarly, many governments have been encroaching on our personal privacy for decades. AI may have put this problem on steroids too, but it is not a new problem.

Autonomy, on the other hand, is an entirely novel problem. We've never had machines before that could make decisions independently of their human masters. Previously, machines only did what we decided they should do. In some sense, machines in the past were only ever our servants. But we'll soon have machines that make many of their own decisions. Indeed, anyone who owns a Tesla car already has one such machine.

Such autonomy introduces some very difficult new ethical questions. Who is accountable for the actions of an autonomous AI? What limits should be placed on an autonomous AI? And what happens if an autonomous AI harms or kills a person, purposefully or accidentally?

A General Motors Cruise self-driving car (below) undergoing testing in San Francisco, US, in 2020. The early promise of autonomous cars soon ran into barriers, and their introduction now seems to have no certain date. Previous pages: Toyota's Concept-i autonomous vehicle on display at the Consumer Electronics Show in Las Vegas, US in 2017.

HAPABAPA/GETTY IMAGES

THE RUBBER HITS THE ROAD

The development of self-driving or autonomous cars is one place where we have seen some of the most detailed discussions around AI and ethics. This is unsurprising. A self-driving car is, in fact, a robot. And we don't build many other robots that can travel at over 150 kilometres per hour.

At present, there are approximately 3 million robots working in factories around the world, and another 30 million or so in people's homes. The total number of robots on the planet is thus slightly higher than the population of Australia. But robots will shortly outnumber all humans, and many of these will be self-driving cars.

A car might not look like a robot, but it is. A robot is a machine that can sense, reason and act. A self-driving car can sense the road and other users on the road. It then reasons about where the car needs to go. And finally it acts, following the road and avoiding obstacles. You can simply sit in the car and say, 'Take me home.' And the car will autonomously do the rest.

Self-driving cars will have profound consequences for our lives. One of the most obvious is improved safety. One million people around the world die in road traffic accidents every year. Over a thousand of these deaths are in Australia. This is a billion-dollar problem in Australia alone, as each fatal accident costs around $1 million to clear up. And that's not counting the human cost.

Globally, road traffic accidents are one of the top 10 major causes of death. In Australia, if you survive past your first birthday, it is the leading cause of death for the rest of your childhood. And almost all road traffic accidents are caused by human error, not mechanical failure. When we eliminate human drivers from the equation, cars will be much safer.

Computers aren't going to drive tired, or drunk. They won't text while driving, or make any of the other mistakes humans make. They're going to be laser-focused on driving. They'll calculate stopping distances exactly. They'll be looking in all directions simultaneously. They'll devote their vast computational resources to ensuring that no accidents occur.

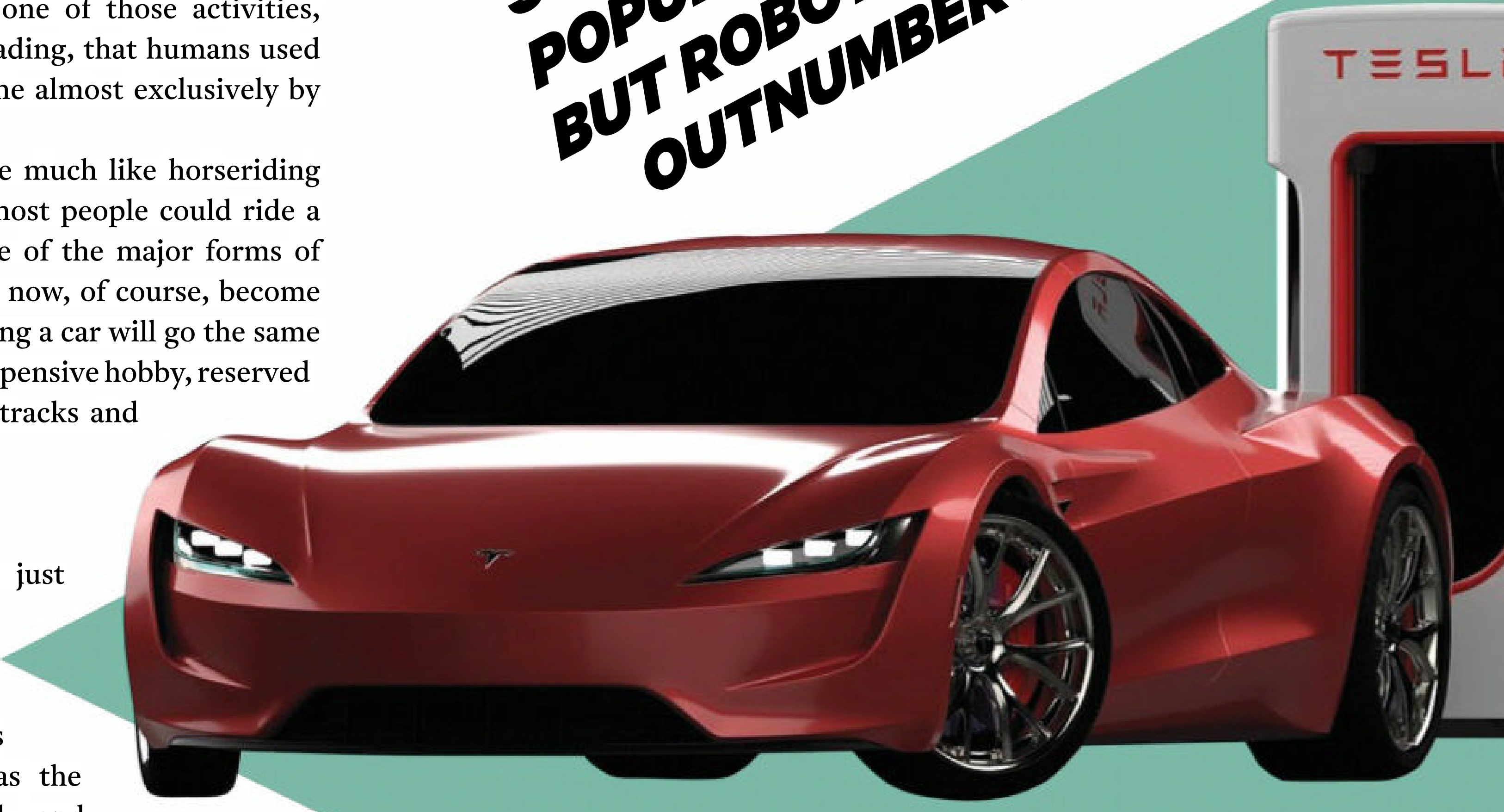
In 2050, we'll look back at 2000 and marvel at how things were. It'll seem like the Wild West, with people driving cars and having accidents all the time. Often, we underestimate the rate of change. Wind back the clock to 1950 and the roads of Sydney looked much as they do today: full of cars, buses and the odd tram. But go back to 1900 and things were very different. It was mostly horses and carts. The world can become almost unrecognisable in less than 50 years.

By 2050, most of us won't drive. Indeed, most of us won't be able to drive. Young people won't have bothered to learn to drive.

They will go everywhere in self-driving Ubers, which will be as cheap as buses. And old people like me will go to renew our driving licences only to discover we haven't had enough practise recently. Driving will be one of those activities, like subtraction or map reading, that humans used to do but that are now done almost exclusively by computers.

Driving in 2050 will be much like horseriding today. It used to be that most people could ride a horse – indeed, it was one of the major forms of transport. Horseriding has now, of course, become a pastime of the rich. Driving a car will go the same way by 2050. It will be an expensive hobby, reserved for special places like racetracks and tourist destinations.

THE TOTAL NUMBER OF ROBOTS ON THE PLANET IS SLIGHTLY HIGHER THAN THE POPULATION OF AUSTRALIA. BUT ROBOTS WILL SHORTLY OUTNUMBER ALL HUMANS



Seeing red? A Tesla Roadster and eponymous charger all polished up for a studio photograph in 2020.

MIKE MAREEN/SHUTTERSTOCK

THE UPSIDE

Self-driving cars won't just make driving safer – they'll have a host of other positive benefits. There are multiple groups who will profit – such as the elderly. My father recently and wisely decided he was no longer able to drive. But once we have self-driving cars, he'll get back that mobility he has lost. Another group that will profit are those with disabilities, who will be given the mobility the rest of us take for granted. Similarly, autonomous cars will benefit the young. I'm looking forward to no longer being a taxi driver for my daughter – I'll let our family car take over the responsibility of ferrying her around. And it will be far less worrying for me to know that a self-driving car is bringing her home late at night from a party, rather than one of her newly licensed friends.

Few inventions of the twentieth century have affected our lives as much as the automobile. It has shaped the very landscape of our cities. It has shaped where we live and work. It gave us mass production. The multistorey car park. Traffic lights and roundabouts.

Cars take us to work during the week. To leisure activities at the weekend. And out to the country in the holidays. The self-driving car will likely redefine the modern city.

No longer will the commute to work in the morning and to home at night be 'wasted' time. We can use this time in our self-driving cars to clear our emails, to video-conference with our colleagues, even to catch up on sleep. Living in the suburbs or the country will become more attractive. This will be a good thing, as many of us will no longer be able to afford the ever-inflating property prices of the city centre.

It's easy to describe the primary effect of self-driving cars: we won't be driving anymore. But the secondary effects may be even more interesting. A continuation of the real estate boom in the country kickstarted by the COVID-19 pandemic? Inner cities as places of entertainment rather than of office work? Cars as offices? Might we stop buying cars all together, and just purchase time on some super-Uber self-driving car-sharing service?

Personally, I hate driving. I find it a waste of time. I can't wait to hand over control to a computer, and get back the hours I now spend driving. My only concern is when I'll be able to do so safely.

THE DOWNSIDE

In May 2016, 40-year-old Joshua Brown became the first person killed by a self-driving car. His Tesla Model S was driving autonomously down a highway near Williston, Florida, when an 18-wheel truck pulling a trailer full of blueberries turned across the car's path. It was the middle of a bright spring day.

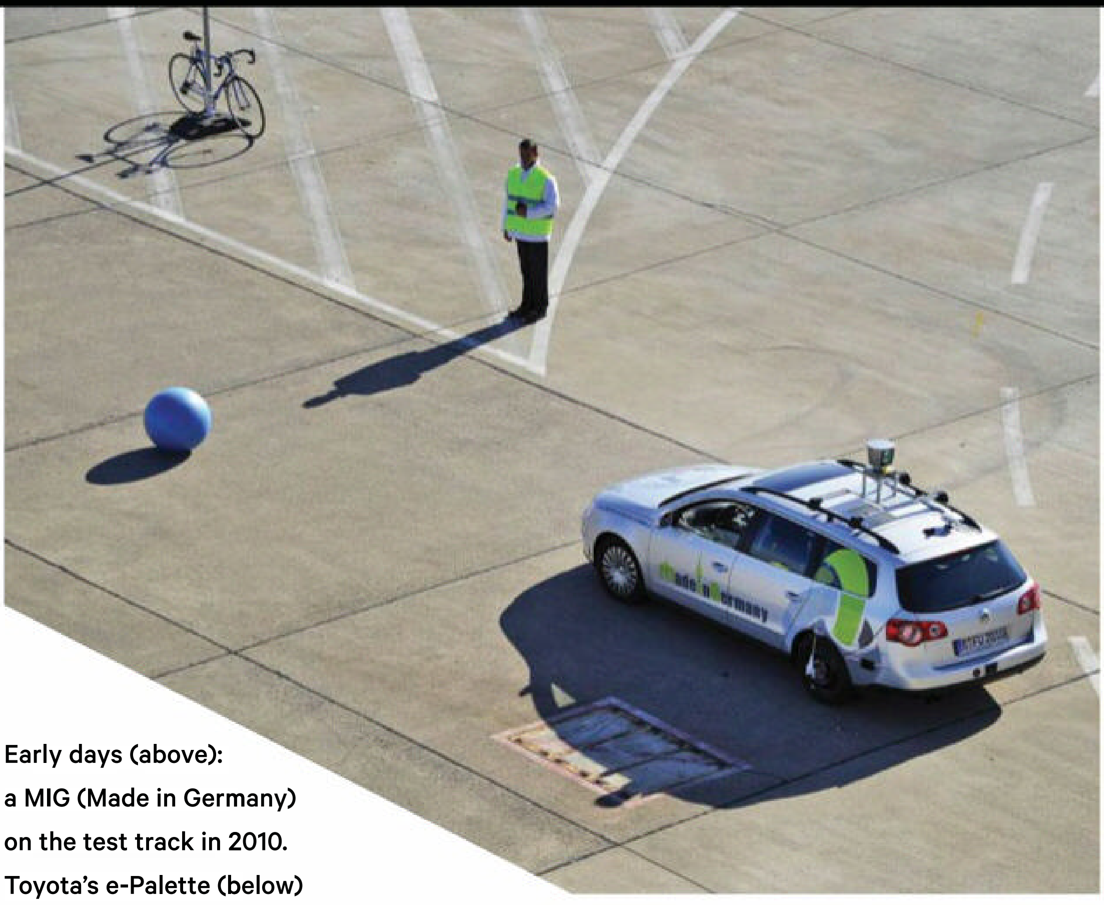
Unfortunately, the radar on the Tesla likely confused the high-sided vehicle for an overhead sign. And the cameras likely confused the white trailer for the sky. As a result, the car didn't see the truck, did not brake, and drove into the 16-metre-long refrigerated truck at full speed. Actually, it was at more than full speed. The Model S was driving nearly 15 kilometres per hour faster than the road's speed limit of 105 km/h. You may be surprised to know that Tesla's 'Autopilot' lets you set the car's speed significantly above the speed limit.

As the two vehicles collided, the Tesla passed underneath the truck, with the windscreen of the Tesla hitting the bottom of the trailer. The top of the car was torn off by the force of the collision. The Tesla ran on and into a power pole. Joshua Brown died instantly from blunt force trauma to the head.

By many accounts, Joshua Brown was a technophile, an early adopter of new technologies. But like many of us, he appears to have placed a little too much faith in the capabilities of such new technologies. A month earlier, a video of his Tesla on Autopilot avoiding a collision with another truck caught Elon Musk's attention. Joshua Brown tweeted ecstatically:

@elonmusk noticed my video! With so much testing/driving/talking about it to so many people I'm in 7th heaven!

Joshua Brown's hands were on the wheel for only 25 seconds of the 37 minutes of his final journey. The Autopilot system warned him seven



Early days (above): a MIG (Made in Germany) on the test track in 2010. Toyota's e-Palette (below) was touted in 2018 as a communal taxi, delivery truck – or mobile shop.

IT DIDN'T HELP THAT WHEN THE ALARM FINALLY WENT OFF, THE SAFETY DRIVER WAS WATCHING AN EPISODE OF THE VOICE ON HER MOBILE.

ODD ANDERSEN/AFP VIA GETTY IMAGES; TOYOTA

Signed in 2016, Volvo and Uber's agreement to create a driverless car (below) was worth US$300 million.

times before the fatal crash to place his hands back on the wheel. And seven times he removed his hands from the wheel. According to the Associated Press, the truck driver involved in the accident reported that Brown was actually watching a Harry Potter movie at the time of the crash. The police recovered a portable DVD player from the car.

In fact, Joshua Brown might not have been the first person killed by a self-driving car. Four months earlier, Gao Yaning, aged 23, died when the Tesla Model S that he was in drove into a road sweeper on a highway 480km south of Beijing in January 2016. However, that crash caused so much damage that Tesla claimed it could not determine if the Autopilot was engaged or not. There have been several more fatal accidents involving self-driving cars since then.

It was inevitable that a self-driving car would eventually kill an innocent pedestrian or cyclist. I made such a prediction at the end of 2016 in a list of AI trends for the coming year. It took just over a year for my prediction to come true.

In Tempe, Arizona, in March 2018, a self-driving Uber test vehicle struck and killed Elaine Herzberg, a pedestrian pushing her bicycle across the road.

There were both technical and human reasons for this fatal accident. Uber's self-driving system sensed the woman nearly six seconds before the impact. But the system failed to classify her as a pedestrian. She was crossing at a location without a pedestrian crossing, and the system had been set to ignore jaywalkers as it was giving too many false positives. The software also kept changing its classification of her – was she a vehicle? A bicycle? An unknown object? – preventing the car from braking or steering away.

When the self-driving car finally sounded the alarm to instruct Uber's safety driver to intervene, she had only a fraction of a second in which to react. This is where human factors came into play. It didn't help that when the alarm finally went off, the safety driver was watching an episode of *The Voice* on her mobile phone. She was subsequently charged with homicide and is awaiting trial.

The National Transportation Safety Board investigators looking into the accident were highly critical of Uber. They determined that the Arizona testing program lacked a formal safety plan, full-time safety staff and adequate operating procedures. Uber had also reduced its test drivers from two to one per vehicle just five months before the accident.

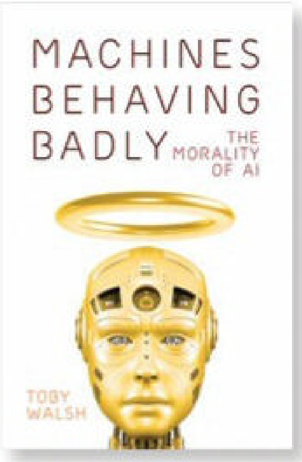
"Ultimately, AI will be a pervasive and critical technology, like electricity, that invisibly permeates all aspects of our lives."
– Toby Walsh, Scientia Professor of AI at UNSW Sydney.

On the day of the Uber accident, the 3000 people who were killed in other road traffic accidents – those involving human-driven cars – didn't make headlines around the world. Nor did the thousands of safe kilometres that other self-driving cars drove that day.

But then neither did the report that an Uber engineer sent to Eric Meyhofer, the leader of Uber's self-driving car project.

Less than a week before the accident, the engineer's report warned about serious safety problems at Uber. "We shouldn't be hitting things every 15,000 miles," the engineer wrote.

Except it wasn't just a thing that Uber was about to hit in March 2018. It was Elaine Herzberg. ⊙



TOBY WALSH'S *Machines Behaving Badly* ($32.99) was published in May by La Trobe Unversity Press. His other books include *2062: The World That AI Made.*

VOLVO CARS; COURTESY LA TROBE UNIVERSITY PRESS

A recent paper shines a light on the evolution of monotremes. For experts, it raises as many fascinating questions as it solves, writes **KEN EASTWOOD.**

Our ancient mammal mystery

It's a detective story – a monumental mystery – that involves quite a few bizarre elements. There's a cubic metre of chocolate; a giant, tree-climbing echidna; an ancient tiny creature snuffling around a dark forest near the South Pole; and a 3000-year-old Israelite called Samson. There's hard slog, serendipity, and shovelfuls of sand. There are millennia of mystery, with palaeontological royalty undertaking guesswork and uncovering solid evidence over the past 25 years. And out of it all comes some of Australia's most extraordinary mammals – the egg-laying platypus and echidna.

Tachyglossus 1.6 mya – present
0 molars; 7kg

Zaglossus 1.8 mya – present
0 molars; 15kg

Ornithorhyncus 3.8 mya – present
0 molars; 2.4kg

PETER SCHOUTEN / AUSTRALIAN MUSEUM

The gradual uncovering of the evolution of these monotremes has culminated in a paper released this year in *Alcheringa: An Australasian Journal of Palaeontology*.

The research, headed by the Australian Museum's chief scientist Kristofer Helgen and honorary associate Tim Flannery, has set out to explain how every significant monotreme fossil currently known fits into the evolutionary story, from a tiny shrew-like creature in Antarctica 130 million years ago to the present day.

* * *

We could start this ripping yarn almost anywhere over that period, but let's close in on the 1960s, when budding American scientist Tom Rich is studying palaeontology at the University of California, Berkeley, and meets his future wife, fellow palaeontologist, Pat Vickers (now Vickers-Rich). Listening to their lecturer Professor Ruben Arthur Stirton, who had done pioneering palaeontological work in Australia in the 1950s and '60s, helped stir their interest in things Australian, and would help Tom and Pat towards Australian citizenship and careers in which they'd uncover more of Australia's ancient creatures of the dinosaur period than almost anyone else.

"If we'd stayed in North America, we would have been following in other people's footsteps, but coming here, we were pioneers – that's a real privilege," says Rich, who is now curator of vertebrate palaeontology for Museums Victoria.

But the couple didn't start out as instant successes. "I first came out with Pat in 1974 and with our North American experience, we just didn't find any fossils," he says. "It didn't pour of the rock. But gradually we learnt what to look for and we were determined to find it."

Rich pulls out a chart that illustrates how miniscule the Australian fossil record of Mesozoic mammals is. The North American, European and Asian fossils from that period are relatively abundant; the Australian record barely registers on that scale. In fact, it took 23 years of looking for Australian Mesozoic mammals before Rich would find his first specimen.

Kristofer Helgen puts into context how rare such mammal fossils are in Australia: "In Wyoming or Siberia, a little mammal bone might be put in a box to look at later, but in Australia, to the fossil researcher, that's a much, *much* more exciting thing than gold or diamonds."

In the 1970s and '80s, palaeontologists such as Tim Flannery and John Long began looking for Mesozoic fossils along the south-eastern Victorian coastline, because that's where Australia's first dinosaur bone – the toe of a carnivorous dinosaur – was discovered in 1903. As they pored over geological maps of Victoria, they realised there should be multiple potential sites with rocks the right age, so they searched along the southern coast from Melbourne towards Cape Otway, eventually finding the site they'd call Dinosaur Cove.

"We spent 10 years there collecting and got a lot of dinosaurs, but no mammals," Rich says. It became part of the annoying mystery – there were reptiles and amphibians, fish and birds, but where was the mammalian community?

In their book *Dinosaurs of darkness*, Rich and Vickers-Rich pay tribute to more than 700 volunteers who came to help dig during the excavations, many of them returning multiple times to do the hard yakka on the end of a jackhammer or shovel. "It was very labour intensive, with 15–20 people working at a time," Rich says. "If we didn't have these people the stuff would still be in the ground. It was a helluva lot of people doing a helluva lot."

Australian Museum honorary associate Tim Flannery (below, with *Steropodon* jaw) was a co-author of the new paper re-examining monotreme evolution. Previous page: *Murrayglossus hacketti*, the extinct giant echidna, grew to about 1m in length and weighted about 30kg – it's the largest known monotreme. Until the new study it was regarded as a long-beaked echidna, but is now the sole species in its own genus.

> "Essentially all mammals can be identified by their teeth. When we zoom in to look closely at the teeth, we can see where the fossil fits in."

LEFT: JAME ALCOCK / AUSTRALIAN MUSEUM

One repeat volunteer, Helen Wilson, asked him what he would do if she found a mammal bone. “I knew she was a chocoholic so I said, ‘I’ll give you a cubic metre of chocolate’,” Rich says.

When part of a 106-million-year-old mammal humerus and tooth was eventually identified, three years after being dug up in 1993, Rich fulfilled his promise, thanks to another volunteer who knew a bloke who managed a Cadbury factory.

“They couldn’t actually give us a cubic metre of chocolate, but instead presented us with a cubic metre of cocoa butter,” he says. “Then they opened these doors and there were all these chocolates inside and they said, ‘take whatever you want’.”

In 2005, Rich and Vickers-Rich’s paper came out describing that bone, which they identified as a monotreme. They named it *Kryoryctes cadburyi*.

Meanwhile, an exposed rock platform near Inverloch, unromantically called Flat Rocks, was explored and found to have lots of fossils about 20 million years older than the nearby Dinosaur Cove site. “The site is exposed twice a day at low tide. Sand gets washed into the excavation, so you end up having to shovel out sand for a couple of hours before you can start work,” Rich says.

Composed of hard sandstone with a bit of clay, the deposit represents a channel, which animals are thought to have been washed down. And gradually, the long-awaited-for mammal bones began to appear – mainly jawbones and teeth. By 2013 almost 50 mammal jawbones had been uncovered from Flat Rocks.

“You may wonder why we usually find jawbones,” Rich says. “Well, a fresh jawbone is the toughest bone in the mammalian skeleton. I wrote a paper about it and called it the ‘Samson effect’ – Samson was the one who killed 2000 Philistines with a jawbone.”

* * *

Teeth are an incredibly useful tool in identifying mammals, Kristofer Helgen says. “The mammal palaeontologist has to be comfortable with being a detective with very little forensic evidence. We can’t see mammary glands in the fossil record, so we make inferences based on the teeth and jawbone.

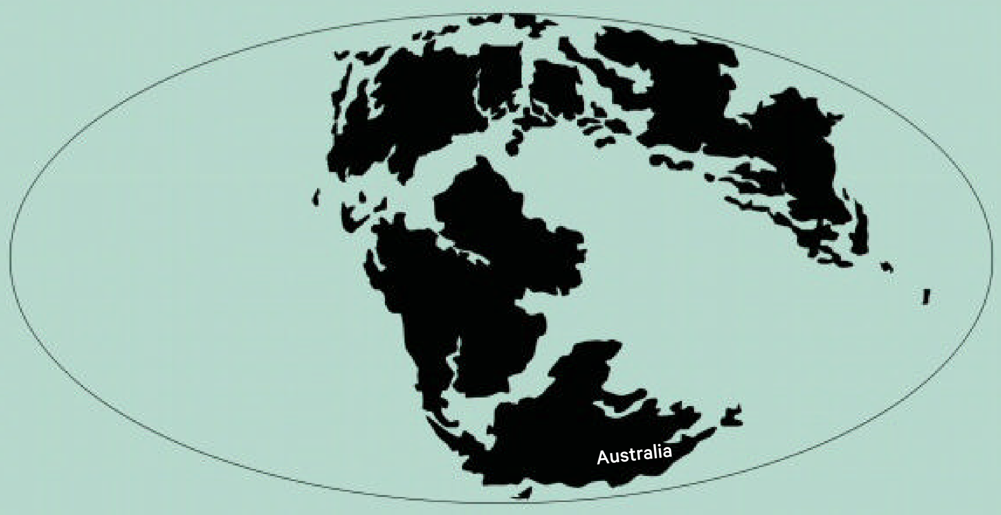
“Essentially all mammals can be identified by their teeth. Birds don’t have teeth, and reptilian teeth are very simple. When we zoom in to look closely at the teeth, we can see where the fossil fits in.”

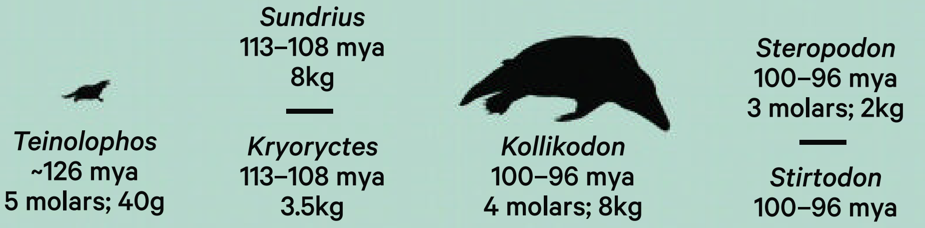
Continual advances in micro-CT scanning and 3D imaging techniques have helped in this identification. Jawbones and teeth also have an inbuilt clue to help identify when they are a monotreme. “They have almost like an excavated canal running along the length of the jaw and teeth,” Helgen says.

That canal carries the nerve system for the electromagnetic sensory system that a platypus has

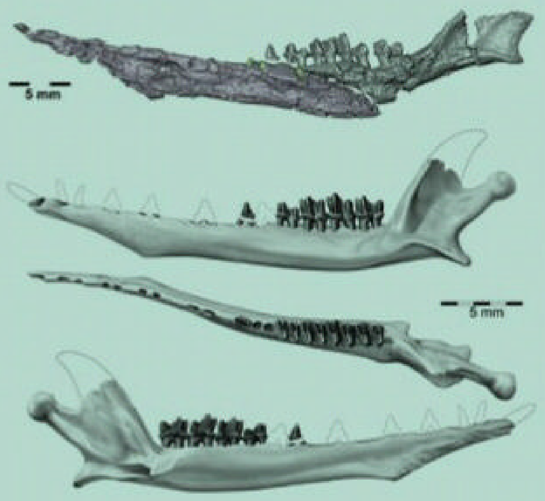
ILLUSTRATIONS RIGHT: TIMOTHY F. FLANNERY, THOMAS H. RICH, PATRICIA VICKERS-RICH, TIM ZIEGLER, E. GRACE VEATCH & KRISTOFER M. HELGEN (2022) A REVIEW OF MONOTREME (MONOTREMATA) EVOLUTION, ALCHERINGA: AN AUSTRALASIAN JOURNAL OF PALAEONTOLOGY, 46:1, 3-20, DOI: 1010.1080/03115518.2022.2025900

JURASSIC–EARLY CRETACEOUS
180 MILLION YEARS AGO (mya)





The earliest known monotreme is a tiny creature named *Teinolophos trusleri*. Its first fossil was found near Flat Rocks, in south-eastern Victoria; subsequent finds have given palaeontologists a complete jaw (below).



When *T. trusleri* was extant about 130 million years ago (mya), the landmass we now call Australia was close to the South Pole and connected to Antarctica. The land was shrouded in rainforest that was dark for a season each year.

For this the reason, scientists believe this 40g animal – about the weight of a slice of bread – may be the monotreme ancestor that developed an electro-sensitive and/or mechano-sensitive ‘bill’ or ‘beak’.

The fossil record is blank for about 20 million years after *Teinolophos*, then an assortment of early monotremes occur, including *Kollikodon* (ca. 100.2–96.6 mya), a relative giant at an estimated 4–8kg, and *Steropodon galmani* (ca. 100.2–96.6 mya) – the first Mesozoic mammal discovered from Australia, and known from a opalised jaw discovered at Lightning Ridge, NSW, in the 1980s.

Illustration of *Kollikodon*

Opalised *Steropodon* jaw

in its bill, allowing it to 'see' its prey even in a muddy creek. "It's like a sixth sense," Helgen says, "and the bigger that canal is, the more sensory capability it's carrying."

At Flat Rocks in 1997, one tiny mammal jawbone was giving the fossil hunters a bit of trouble – it was bound tightly in surrounding rock and couldn't be easily extricated. So Rich brought out an old mate, an expert preparatory specialist from the US, to work on it.

"At that stage we had very few mammals, so I thought it was worth a round trip for him to prepare this one specimen."

But that specimen was so difficult to extract from its matrix that the preparatory specialist asked to have a break by working on something else. He picked up a small specimen to clean that had been misidentified and cast aside. "He was able to clean the crown of the tooth and soon as we saw it, we realised it was a monotreme," Rich says. "Once it was cleaned it was obvious to everyone."

It turned out to be the oldest monotreme ever discovered – a tiny, 130-million-year-old creature that was named *Teinolophos trusleri.* "Over the years we found more and more of this thing and we now have a complete jaw," Rich says.

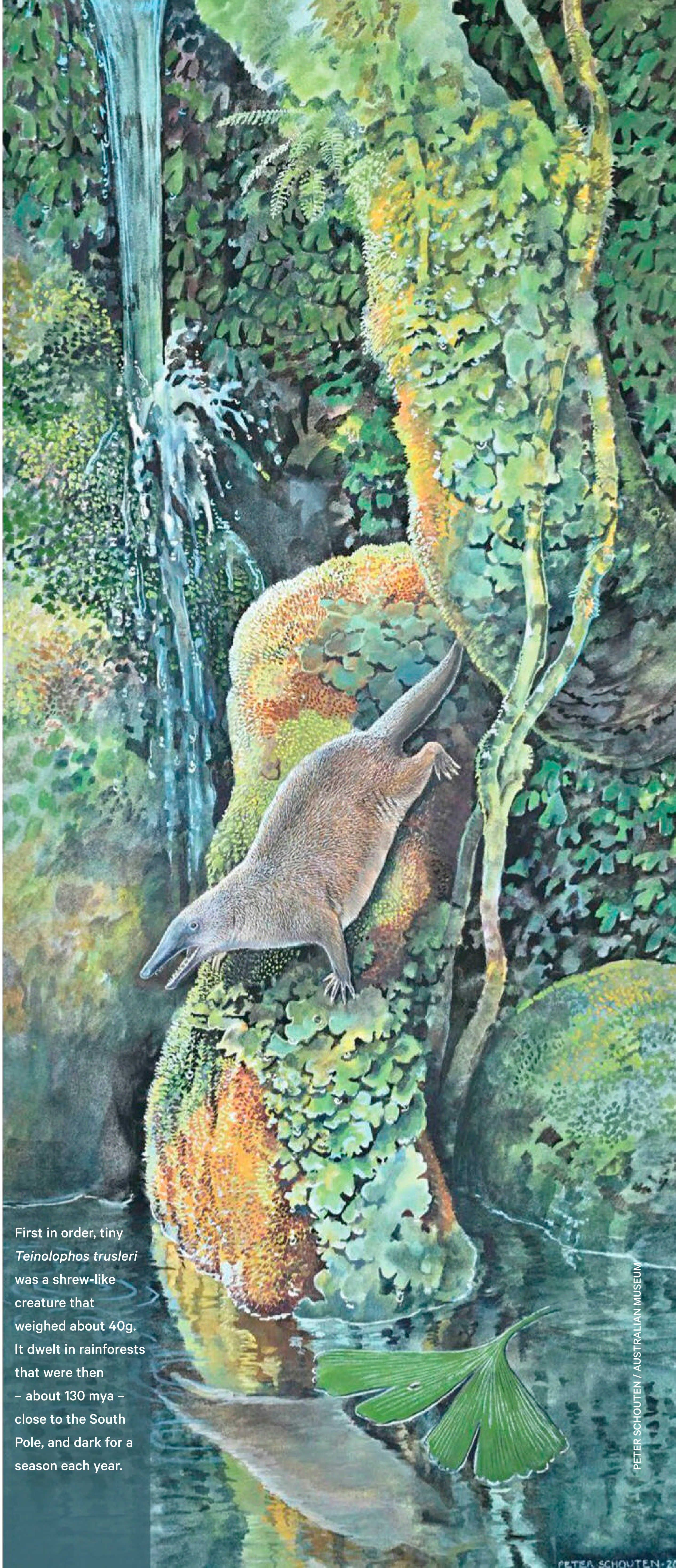
One hundred and thirty million years ago, the continent we now know as Australia was located much closer to the South Pole and completely connected to Antarctica. The thick rainforests of that era were in darkness for three months of the year. The latest scientific paper suggests that this earliest period of monotremes, which lived on land, may have developed their special electro sensitivity to hunt in the dark forests for insects. "If you're going to develop this extra sense, that's a good place to develop it," Helgen says.

"This is an incredible survival adaptation for this mini monotreme, which we estimate had a body mass of approximately 40g – roughly the weight of a slice of bread," Tim Flannery adds.

* * *

As scientists have followed the evolution of monotremes through the growing fossil record, from 11 extinct genera towards the three extant today (platypus, short-beaked echidna and long-beaked echidna of New Guinea), they notice a major change.

"One of the big trends of monotreme evolution is that they go from very toothy to no teeth at all," Helgen says. *Teinolophos trusleri* had five molars, then the number of molars gradually diminishes until they lose them altogether. "Echidnas have no teeth whatsoever, although their tongue has thousands of sharp ridges on it that can function a bit like teeth," Helgen says. "All platypuses prior to the modern one do have teeth, but the modern platypus only has baby teeth – a very unusual set of teeth. They're so rudimentary that they don't develop into hard teeth."



First in order, tiny *Teinolophos trusleri* was a shrew-like creature that weighed about 40g. It dwelt in rainforests that were then – about 130 mya – close to the South Pole, and dark for a season each year.

PETER SCHOUTEN / AUSTRALIAN MUSEUM

Genetic analyses show that four of the eight key genes involved in mammalian tooth development have been lost in modern platypus and echidnas. According to Helgen, ancient egg-laying monotremes are part of the bridge between reptiles and mammals. There are several mammal-like reptiles from that era, including the therapsids, but fewer reptile-like mammals.

"Monotremes have always captured the imagination of biologists," he explains. "They have the least mammalian features and the most reptilian. I call them 'the other way to be a mammal'. For example, they have fairly low body temperatures [the modern platypus' is around 32°C], and they can fluctuate a bit. Then they have sex chromosomes completely different to other mammals and more like reptiles."

Rather than just two chromosomes determining gender, they have multiple. Echidnas also have a four-headed penis, which functions like (paired) reptilian hemipene.

"And just look at them," Helgen says. "They have a splayed posture – the legs kind of come off the side and then down, more like a lizard than, say, a dog or a horse. Also their bone structure is different to most mammals, almost like they have a pelvis in their upper body as well.

"But they are mammals, because fundamentally they feed their young with milk. That's what really sets mammals apart from everything else."

One of the scientific advances in recent years that has helped piece together monotreme evolution has been the mapping of their entire genomes, with the platypus genome published in *Nature* just last year.

Helgen says this has provided new insights. "One of the things that's pretty clear is that platypus and echidnas have been on distinct evolutionary lines for tens of millions of years."

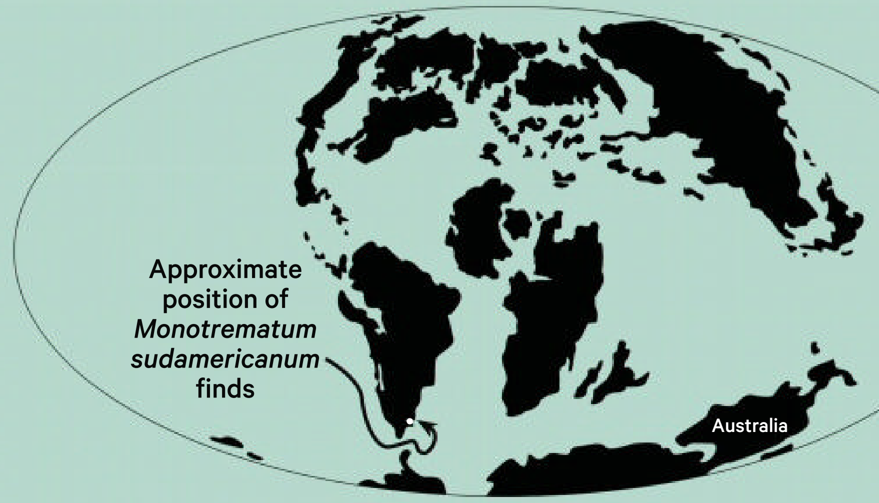
UNSW professor of molecular biology Merlin Crossley, an Australian Museum honorary associate, says genome mapping of all marsupials is gradually being completed. "Over time they will be done and our digital view of the kingdom of life will be very rich and will all be searchable and comparable," he says.

Crossley says such genetic information can help date evolutionary divergence through what's nicknamed the "molecular clock". It comes through looking at non-essential parts of the genome.

"Basically what happens in a gene, just like anything – let's say a car – the main things don't change over time. A car will always have wheels, doors, etc, but the colour of the car changes, the number of the doors can change. It's the same with genes. There are parts that are almost identical, but

ILLUSTRATIONS RIGHT: TIMOTHY F. FLANNERY, THOMAS H. RICH, PATRICIA VICKERS-RICH, TIM ZIEGLER, E. GRACE VEATCH & KRISTOFER M. HELGEN (2022) A REVIEW OF MONOTREME (MONOTREMATA) EVOLUTION, ALCHERINGA: AN AUSTRALASIAN JOURNAL OF PALAEONTOLOGY, 46:1, 3-20, DOI: 1010.1080/03115518.2022.2025900

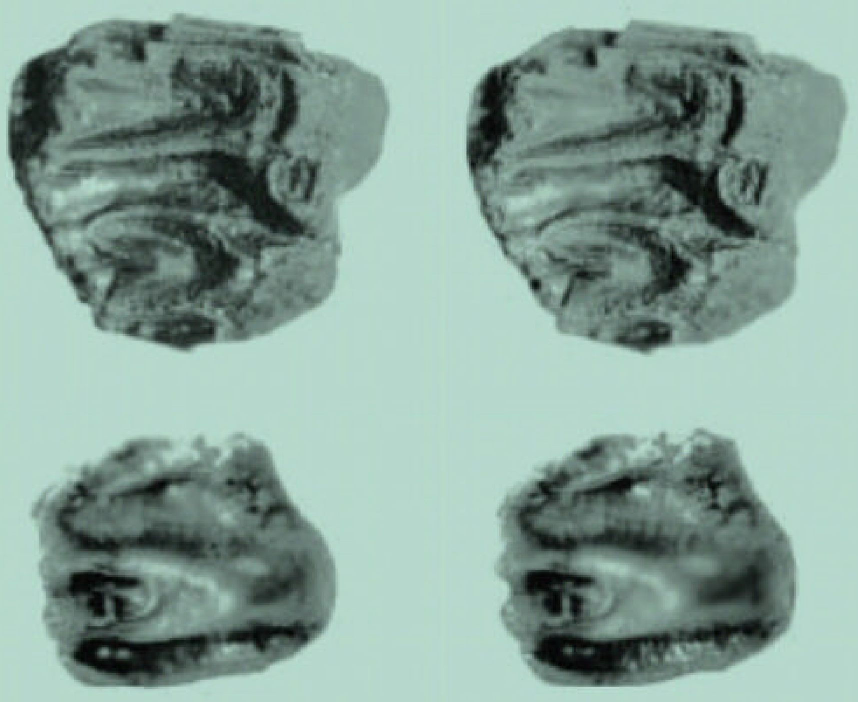
PALEOCENE
~66 MILLION YEARS AGO



Monotrematum
61–63 mya
2 upper and 3 lower molars; 4kg

On its own both geographically and in terms of geological time, *Monotrematum sudamericanum* – the Patagonian platypus – is the monotreme ancestor from another world. "We describe here the first undoubted non-Australian monotreme," wrote its joint Argentinian and Australian discoverers in their 1992 paper introducing it. "This discovery … ends the longstanding monopoly the Australian Region (Australia, Tasmania, New Guinea) has held on monotremes."

M. sudamericanum is known from only two lower teeth (below) and one upper tooth, all discovered at Punta Peligro in the south-east of Argentina's Chubut province – about 1400km south-west of Buenos Aires. The Patagonian platypus was extant about 63–61 mya, after the Cretaceous/Tertiary extinction event and several million years before the period it's thought that platypus and echidnas may have diverged. There's a gap in the monotreme fossil record of more than 30 million years preceding the emergence of *M. sudamericanum*, and one of 35 million years after it – until the emergence of platypus ancestor *Obdurodon* about 26 mya.



> “In theory, if we had a great fossil record, we could see platypus and echidna evolving on different lines.”

there’s other bits which gradually change over evolutionary time, and the amount of that change that has occurred can give you the various million years. It’s the amount of change you’ve got in these areas that don’t matter so much – the areas that are not under selective pressure.

“But the other way to date these changes is if you do have these fossils where there’s a common ancestor and have dated the rock around it. We find this one here and this one over here, so we know this one is this old, and the other one is this old. So it’s geological and genetic. And sometimes the dating between the two methods is not exactly the same.”

Crossley says that piecing together the monotreme evolutionary story is “pretty cool”. “Monotremes are pretty special and the interesting findings about the electronic sensing tells us that what we think of as very primitive animals were actually very advanced.”

Among the various interesting creatures in monotreme evolution was a so-called ‘giant’ echidna, *Murrayglossus hacketti*, which was around in the Pleistocene era and is known from fossils discovered in 1912 in Mammoth Cave in south-western Western Australia. The latest research included re-visiting all the original specimens, including the fossils of this 30kg, 1m long creature, and discovering a few more things about it.

“All the original finder knew was that this was a type of gigantic echidna, but everyone who has now looked at this has said it’s very, very different to existing echidnas,” Helgen says. “It wasn’t just so much bigger, but has long, strong legs. The way they’re mechanically put together shows it could stand on its back legs quite strongly. This is a very different way to be an echidna.”

It is considered so different that Murrayglossus was given its own genus in the latest research.

“This was a species around the ice age,” Helgen says. “It lived alongside First Nations people, and animals like Diprotodon and large kangaroos. It’s one of the dozens of species that did become extinct between the time that people first arrived in Australia and the time that Europeans arrived.”

Helgen says that at least three species of echidna lived alongside it, including the modern short-beaked echidna, and they “divided up the landscape, eating different things to make a living, and so Murrayglossus probably took advantage of things that were well off the ground.”

He says that a climbing echidna shouldn’t be considered that unusual. “Monotremes are all muscle. The platypus is like an Olympic swimmer, but the echidna is like the Olympic digger.

“Being so muscular they can take on any obstacle that comes in front of them. Even the modern echidnas are pretty good climbers. Tim and I have watched them climb trees up in New Guinea, and in zoos they get over fences and walls.”

That muscular nature leads to one of the biggest mysteries in the evolution story. Big muscles usually means strong bones – bones that last. “Echidnas fossilise really well, because their bones are super robust,” Helgen says.

And yet, there are no echidnas in the fossil record until about 2 million years ago – relatively recently in the palaeontological record – leaving almost a 100-million-year gap between those early monotremes and today’s echidnas.

Kristofer Heglen, lead scientist, Australian Museum.

An educational resource for this story is available at **www.education.australiascience.tv**

FROM TOP: JOHN CARNEMOLLA, KRISTIAN BELL/GETTY IMAGES. UNIVERSITY OF ADELAIDE

"In theory, if we had a great fossil record, we could see platypus and echidnas evolving on different lines. But there is almost no fossil record for echidnas prior to the modern ones," Helgen says.

This led Helgen and Flannery to develop a hypothesis that is perhaps the most controversial part of their latest paper, because it is a theory based on absence of evidence rather than actual evidence.

In asking themselves "where could the ancient echidnas be?" they have come to the conclusion that they evolved almost completely in Melanesia, or what we now know as parts of New Guinea, where there are very few fossil sites and little palaeontology has been done. "In tropical areas palaeontology is almost a no go because of the humid soils and high rainfall," Helgen says. "We need to find really protected sites like caves. If you hit on that you'll find a treasure trove."

In the paper, they write that early echidnas could have developed, evolved and diversified on remote islands in that area, once the region had isolated from other landmasses, "inhabiting a tropical, rainforest-covered island [that] would have had extensive areas of humid forest within which to forage. In the absence of competitors, specialisation for a more terrestrial lifestyle could thus have feasibly evolved."

The fossil record shows that many animals moved between New Guinea and the Australian mainland between about five and three million years ago, and the authors propose that's when the echidnas could have moved onto the Australian mainland.

"Once in Australia, the group then radiated into diverse woodland, grassland and arid environments while simultaneously increasing emphasis on olfaction as a primary sensory adaptation for prey detection and capture," they write.

Helgen says we need a new generation of Tom Riches, who are willing to go anywhere in Australia and gamble years or decades of their lives in a commitment to a particular site to find more about our faunal ancestors. "When those sites are found, the discoveries will come," he says.

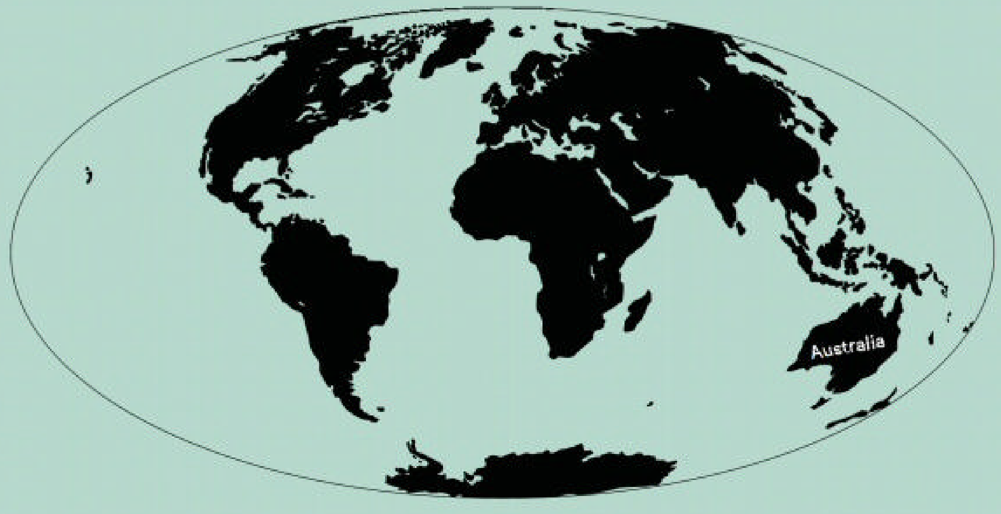
Meanwhile, Rich keeps mulling over something that's been bothering him.

"We know mammals were in the Jurassic, but we've never found them in Australia," he says. "They must have been on this continent, but where you can actually pick one up, I have no idea. I've been thinking about it for 40 years." ◉

KEN EASTWOOD is a Sydney-based science and natural history journalist. This is his first feature for *Cosmos*.

ILLUSTRATIONS RIGHT: TIMOTHY F. FLANNERY, THOMAS H. RICH, PATRICIA VICKERS-RICH, TIM ZIEGLER, E. GRACE VEATCH & KRISTOFER M. HELGEN (2022) A REVIEW OF MONOTREME (MONOTREMATA) EVOLUTION, ALCHERINGA: AN AUSTRALASIAN JOURNAL OF PALAEONTOLOGY, 46:1, 3-20, DOI: 1010.1080/03115518.2022.2025900

MIOCENE –PRESENT

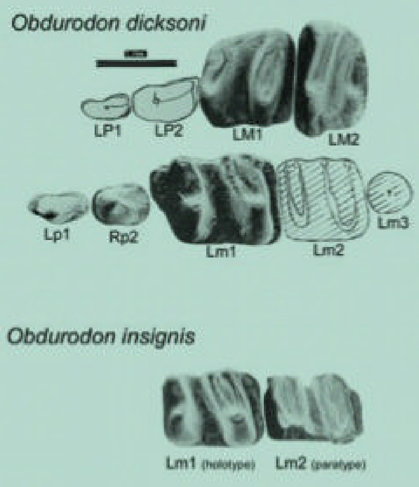


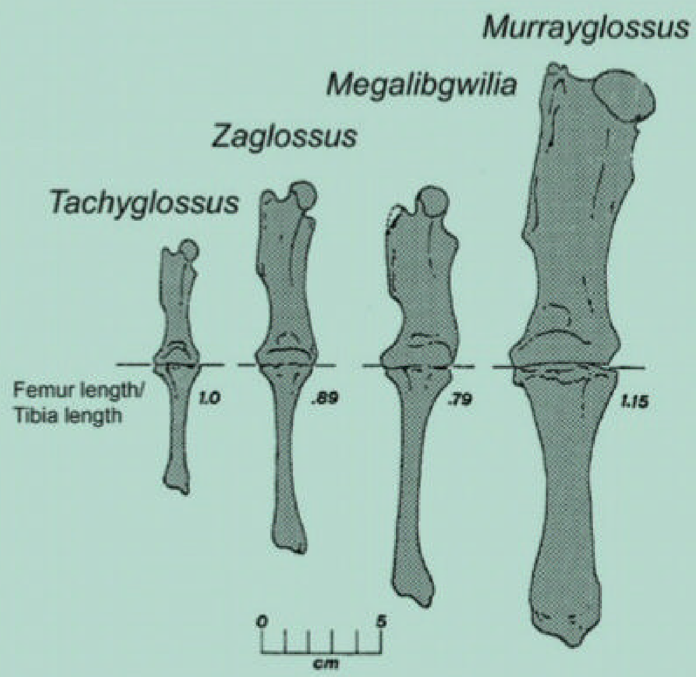
Obdurodon
26–13 mya
2 upper 3 lower molars; 7kg

Murrayglossus
0.1 mya
0 molars; 30kg

Megalibgwilia
1.78 – 0.5mya
0 molars; 15kg

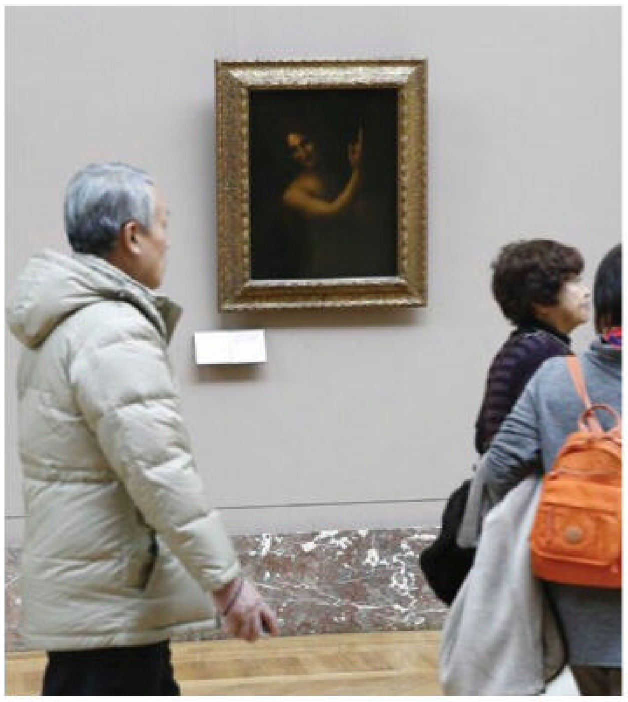
From the Miocene to the present day there's been a relative blossoming of monotreme types, leaving us now with two families and five living species. Family Ornithorhynchidae has a single living species, the platypus (*Ornithorhynchus anatinus*); family Tachyglossidae has four: the short-beaked echidna (*Tachyglossus aculeatus*), found in Australia and New Guinea, and the long-beaked echidnas found only in New Guinea – *Zaglossus bruijnii*, *Z. bartoni* and *Z. attenboroughi*. Known from the fossil record and extant in tantalisingly recent times are the comparatively larger echidnas *Murrayglossus hacketti* and *Megalibgwilia oweni* (a comparison of their femur and tibia lengths to those of surviving species appears below). Absent from their fossils and bones are the feature that mark out all older ancestral monotremes: teeth. *Obdurodon*, which appears in the fossil record from 26 to 13 mya is the most recent toothed genus (right).





THE SCIENCE OF

SUCCESS



Success in any field is about talent and perseverance, right? ANNAMARIA TALAS talks to the researchers whose studies suggest that many other qualities – including luck – play a role.

On a visit to the Louvre, Australian physicist turned sociologist Professor Duncan Watts, from the University of Pennsylvania, US, was puzzled by the mobs of people struggling their way to just one painting, *La Giaconda* – the Mona Lisa. Yet, when he asked his friends and students how they felt about finally seeing the world's most famous painting, there was a sense of anticlimax. Watts doesn't question that the Mona Lisa is a masterpiece. But he believes it's for a totally different reason than that enigmatic smile – and it could explain a lot about success in general.

"The way that people typically explain the success of the Mona Lisa, which is also how they explain the success of most things, is to focus on the attributes of the painting itself," says Watts.

As he points out, even in the Louvre there are other, similar paintings, yet not many people have heard of them. Watts' favourite example hangs nearby: the painting *Saint-Jean Baptiste*.

"It's another painting by Leonardo, but everybody just walks right past it," Watts says. "So, if the Mona Lisa really is the best painting in the world, why does nobody take any interest in a painting that's very similar in style, by the very same artist?"

Art historians usually argue that it's not any one attribute of the Mona Lisa that makes it the best, but all of the attributes together. The problem with that argument, as Watts explains, is that it's effectively saying the Mona Lisa is the most famous painting in the world because it's more like the Mona Lisa than anything else. Unhappy with this circular reasoning, Watts looked back at history of the painting.

"For four hundred years Mona Lisa was spending her life in obscurity," he says. "It only started to get famous after it was stolen [in 1911]. The theft was front page news and for the first time, there were queues outside the Louvre, just to see the empty space where the painting had hung."

Watts wondered: how tightly is success tied to quality, or are there other forces at work? What would happen if Mona Lisa's story had turned out differently? Would it still become the most famous painting in the world? Or would some other work take its place?

We can't rewind history, but Watts and his PhD student at the time, Matt Salganik, devised a way to simulate the idea.

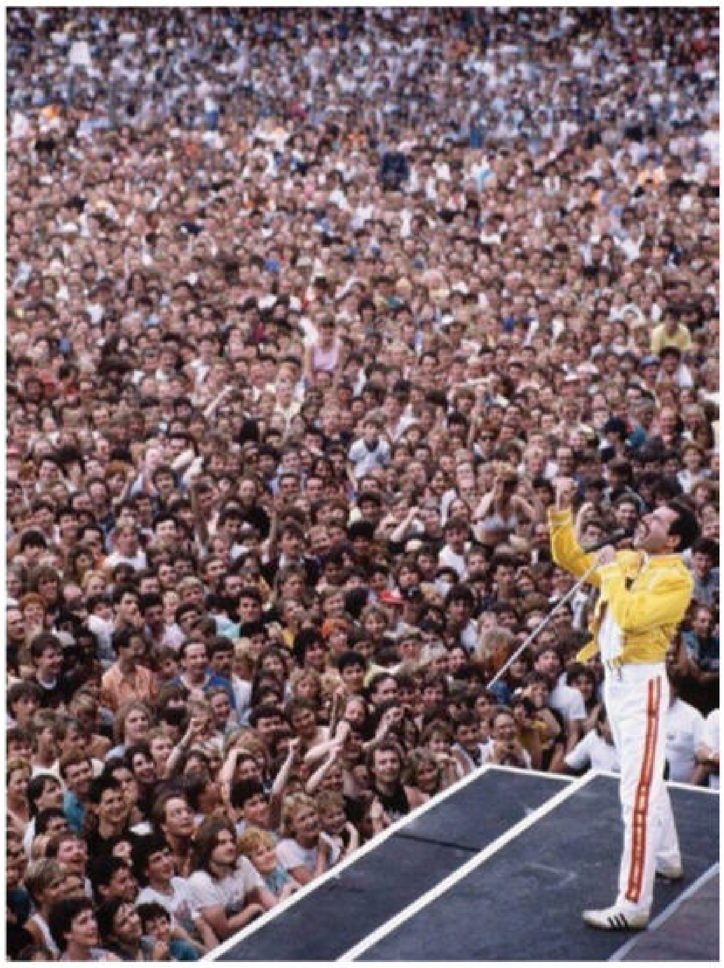
They created a music downloading website called the Music Lab. They identified a group of bands that were good, but who no one had heard of. Thousands of people came to the website, ignorant of the fact that in the background they were randomised into one of two 'treatments'. Those in treatment A saw only the names of the bands and the songs. Those in treatment B also saw a number indicating how many times that song had been downloaded by people who'd visited before them. Treatment B did one more thing: it divided songs into eight different 'worlds'. The download number people saw only referred to downloads in that particular world. All eight worlds started with zero downloads for all songs.

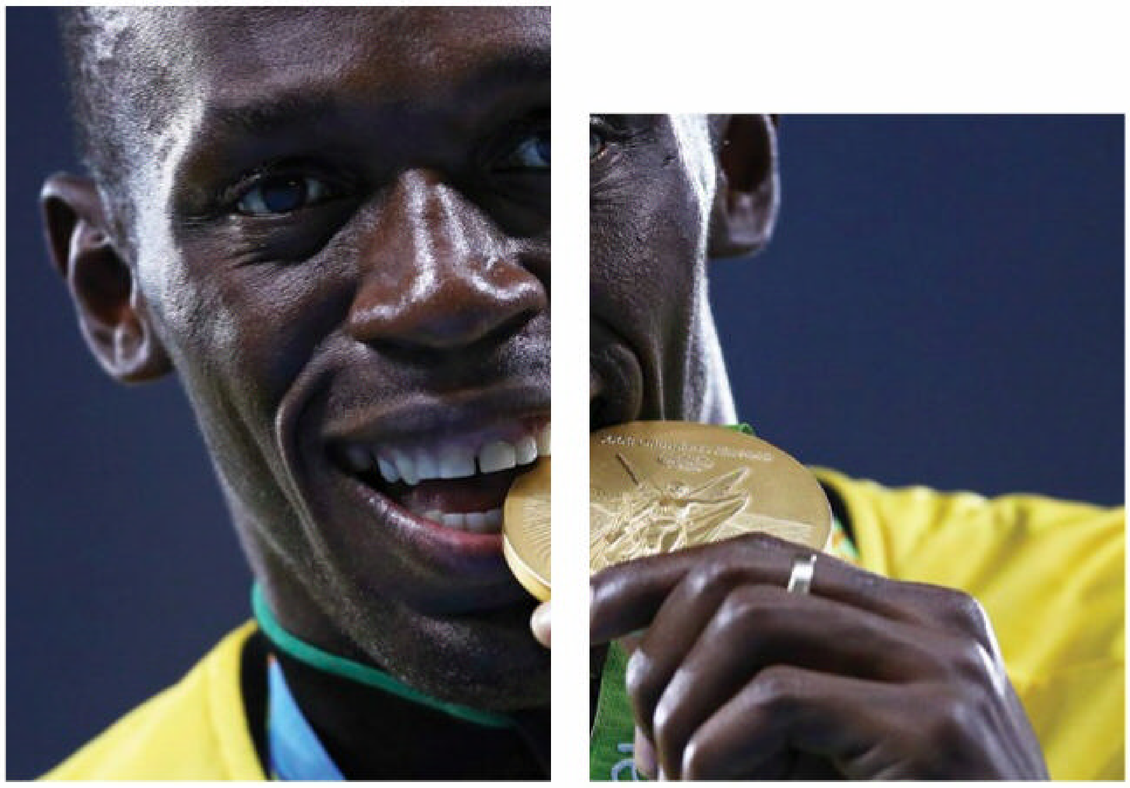
"Going back to the analogy of re-running history over and over again, if the only thing that's going on is that the song has some quality and that's why it's successful, it should do roughly the same in each one of these worlds. In fact, the opposite was true," says Watts.

The results were unambiguous: in each world, where people could see the ratings, a different song became the winner. A particular song that in one world was the most popular came 44th out of 48 songs in another world. The song was exactly the same – clearly, it wasn't (only?) talent that was driving success.

Is the world's most famous painting (opposite) truly better than any other work – such as *Saint-Jean Baptiste* (above right), here ignored by disinterested Louvre guests – its artist, Leonardo da Vinci, created? Modern research suggests that talent doesn't equal success.

FROM LEFT: FEDERICO SCARIONATI / UNSPLASH. PATRICK KOVARIK / GETTY IMAGES





Pure talent, on top of the world? Freddie Mercury (above left) and Queen wow them at Wembley Stadium, London, in 1986; sprinter Usain Bolt (above) chews on another Olympic gold medal – his eighth overall – after winning the men's 4 x 100m relay at the Rio Olympics in 2016.

FROM LEFT: REDDIT. PATRICK SMITH / GETTY IMAGES

"HOW IS IT POSSIBLE THAT TWO ARTISTS START TOGETHER AND PAINT INDISTINGUISHABLE WORK, THEN ONE BECOMES A STAR WHILE NO ONE KNOWS ABOUT THE OTHER?"

"The first people who came along had a big influence in how the trajectories evolved," says Watts. "We could see that relatively quickly the worlds would lock themselves into a particular ranking, which tended to reinforce itself."

The Music Lab experiment suggested that successful paintings, songs and people might not be the best, but the luckiest.

Inspired by Watts' experiment, sociology professor Arnout Van de Rijt, of European University Institute, wanted to test the idea further. He wondered whether Watts' result applied to the real world – not just in an online experiment, To find out, Van de Rijt identified 200 projects on the crowdfunding platform Kickstarter that hadn't received any donations.

"What we did was no different from what anybody who participates on Kickstarter does: look at projects, and decide to donate to some," he says. "The only difference was that we decided by the roll of a dice."

They found a big difference between the lucky and unlucky Kickstarter projects decided by the dice: those that received early donations were twice as likely to succeed. The experiment confirmed in real life Watts's results – a random vote of confidence marked projects for success.

The desire to understand success is a passion of physics professor Albert-László Barabási, of Northeastern University, US. For decades he's focussed on the properties of complex systems such as social networks, the internet and the molecular networks in human cells. Recently, he became interested in a different question.

"We were curious to find out, to what degree does the network affect our success, or when does it pull us back," says Barabási.

Barabási and his colleagues analysed massive data sets: the popularity of professional tennis players, the career paths of 30,000 artists around the world, and all published science studies in the last 100 years.

"Analysing these data sets helped me understand that performance is crucial, but once you reached a certain level of performance, adding 5% more makes no difference," Barabási says. "What matters ... is how you change the perception of your performance in the community. Success is a social phenomenon."

People often use performance and success interchangeably, but that can't be further from the truth.

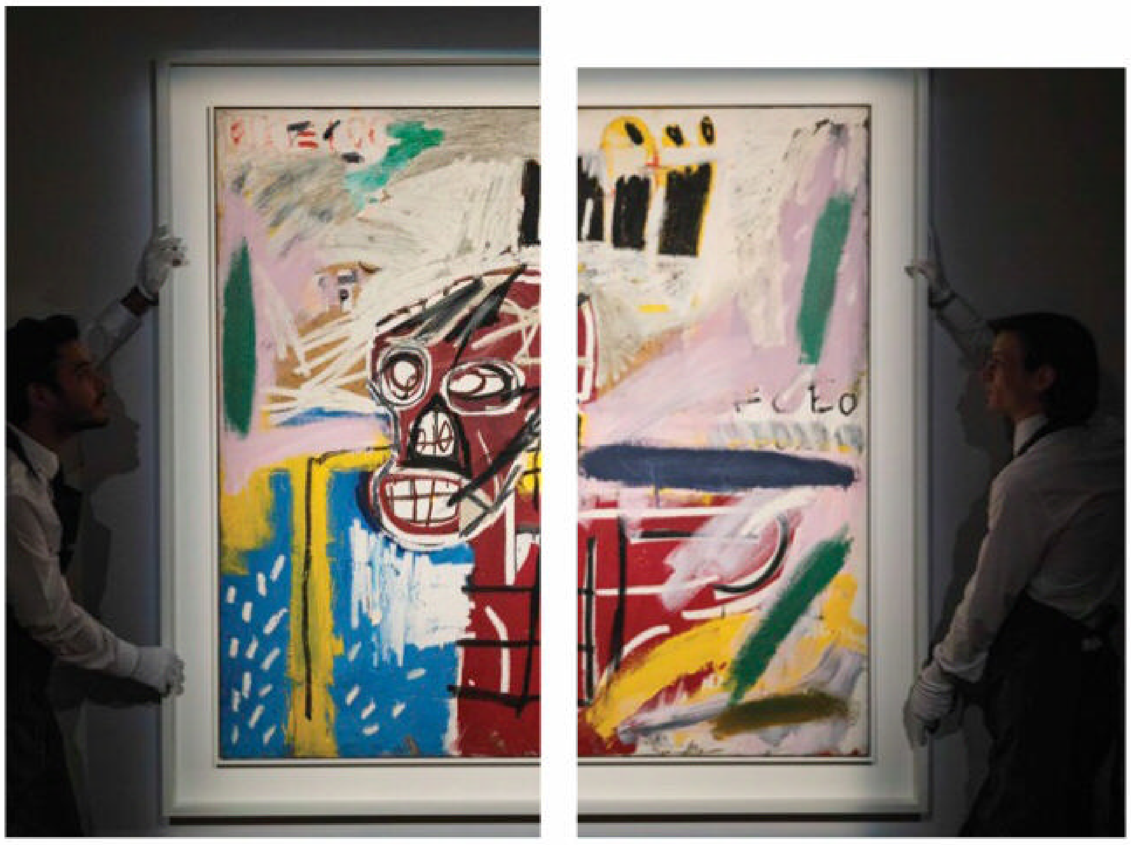
"The biggest surprise for me was that performance and success are mathematically very different," Barabási says.

"Take running. The fastest man on Earth is Usain Bolt. But when you look at his and his competitor's speeds you realise that the difference between the winner and the losers at any competition is typically 1% or less."

Plotted on a graph, athletes' running speeds show up as a bell curves. This means that most have roughly the same performance, and a few are a bit better than average. Mathematically this means that performance is bounded.

"The boundedness of performance has important consequences," says Barabási. "It means that at the top there will be a many individuals whose performance is virtually indistinguishable."

Performance may be bounded, but success is not. It's the hidden reason why we quite often perceive the world as unfair. Tiny differences in performance can easily translate to order-of-magnitude shifts in success. Consider too that many of us work in areas



Jean-Michel Basquiat (above right), shown attending a 1984 benefit concert with Andy Warhol, rose from graffiti artist to international fame. In September 2017, 29 year after Basquiat's death, his painting *Red Skull* (above) sold at auction for US$21.6 million – a little down on the US$110.5 million his work *Untitled* fetched in May the same year. Basquiat's school friend and graffiti-painting partner Al Diaz started with a similar style, but has never enjoyed the same success.

FROM LEFT: JACK TAYLOR, RON GALELLA / GETTY IMAGES

where quality is difficult to measure – invisible forces drive success.

At one point in life, Barabási wanted to be a sculptor, so his interest in art was personal. He was intrigued by the story of two New York street artists whose work was all but identical, yet whose careers took very different trajectories: Jean-Michel Basquiat and his graffiti-painting partner, Al Diaz.

"How is it possible that two artists start together, and paint indistinguishable work, yet one of them becomes a star while no one knows about the other?" asks Barabási. "What makes some artists succeed and others fail?"

Investigating success in the secretive world of art presented a huge challenge, but a few years ago an opportunity presented. One of Barabási's graduate students, Samuel Fraiberger, had a chance encounter with a young art entrepreneur named Magnus Resch.

"He was building an app based on 10 million images and the exhibition history of one million artists," says Fraiberger. "It was designed to make the prices in art transparent. What was fascinating about his dataset is that we could use it to reconstruct the entire history of an artist."

The researchers knew that when performance is hard to measure, who you know becomes more important than performance. What they didn't know was how to reveal that in the data. By tracing how art moved from one exhibition place to the next, Fraiberger started to make visible the unseen connections that link art to museums and galleries. But there was another challenge: how to measure the prestige of the exhibition places? He came up with an ingenious idea.

"It's very similar to what Google does when they classify internet pages," he says. "The search engine is not looking at the content of the page, it's looking at the links of the page to determine how important it is. The idea here is exactly the same. An art institution is prestigious if it's linked to many art institutions that are themselves prestigious. We used this idea to quantify the prestige of each art institution in our data. That quantification allowed us to create a network of the art world."

It was an astonishing map, revealing the hidden structure that governs an artist's success. One highly connected island contained all the high-value institutions, and whenever artists exhibited at one of these institutions, there was an extremely high chance that they'd exhibit at another institution in this core group. This high-value cluster co-existed with many islands that were totally isolated from the centre of the art world, where value is created.

"That was the first glimpse that the art world is unfair – it's extremely hard to become successful," says Fraiberger.

It isn't surprising that the big galleries can make an artist's career; what *was* surprising is that this map could predict an artist's future career.

"If you gave me your favourite artist and the first five exhibits he had, I would place those five exhibits on the map and ... fast forward that artist's career 20 years and tell them where they'll end up," says Barabási. "The maps showed us that the key to success in art is where you start on the map."

And that helps explains Basquiat's trajectory. A born networker, and helped by chance, he very early on met with powerful gallery owners, whose patronage powered his amazing success.

The tangled web of social interactions can now be measured and predicted. The science may be new, but the maths is not. It underpins millions of individual stories, each of which can be understood through this new way of looking at the world. ◉

A documentary by ANNAMARIA TALAS about success is soon to stream on Curiosity.

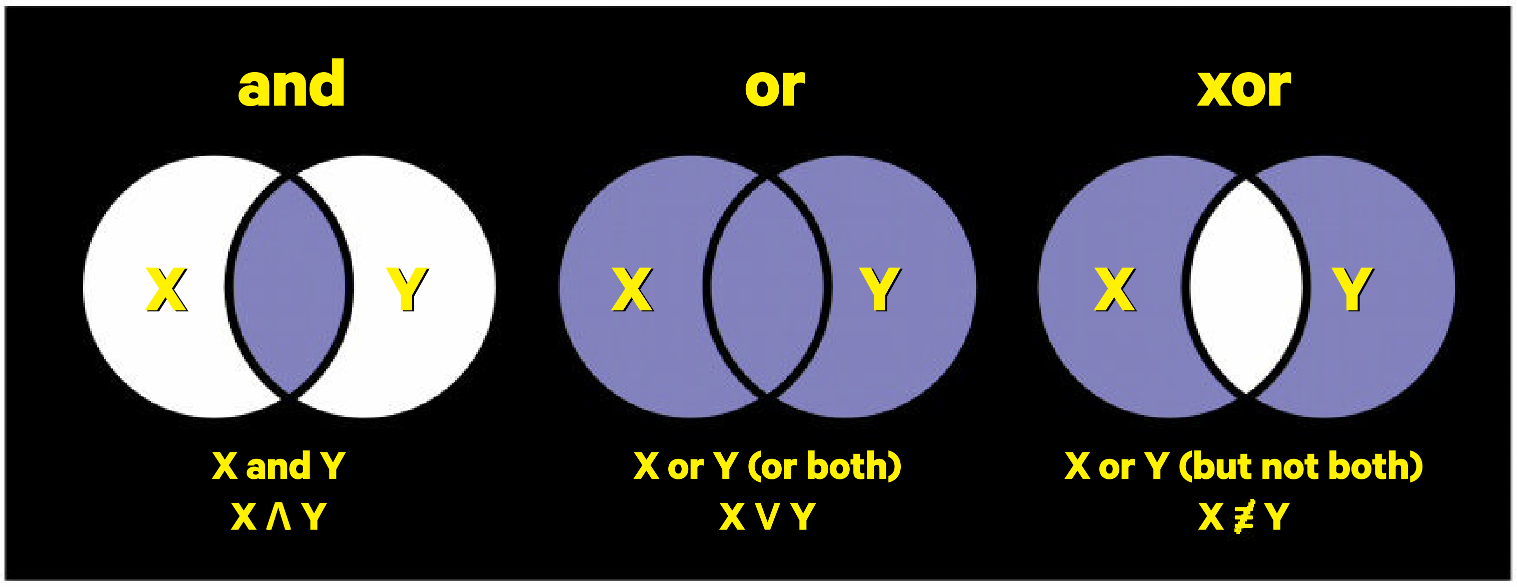
The Art of Logical Thinking

There's a line of logic stretching from Aristotle to artificial intelligence, writes **ROBYN ARIANRHOD**, and standing near its crest is the witty and brilliant Briton Bertrand Russell.

“Every man, wherever he goes, is encompassed by a cloud of comforting convictions, which move with him like flies on a summer day.”

The inimitable British philosopher-mathematician Bertrand Russell, a master of pithy word-images, won the 1950 Nobel Prize for Literature for his vast body of lucid writing on science, philosophy, and social issues. And we can surely forgive his generic use of “man” in this quote, for Russell was born 150 years ago on 18 May, and he was such a supporter of women’s rights that in 1907 he stood for parliament on the risky platform of votes for women.

He wasn’t successful and copped extraordinary vitriol for his efforts – as he did for his advocacy of birth control, for more relaxed attitudes to sex, and for his anti-war protests. But let’s get back to that statement about convictions and flies, and others in a similar vein. “People don’t seem to realise that it takes time and effort and preparation to think,” he noted, adding sardonically, “Statesmen are far too busy making speeches to think.” And here’s another classic, “Many people would sooner die than think. In fact they do.” But these witticisms reflect not hubris, but his passionate interest in thinking. Not just any old thinking, either, but how to think *logically*.



“It is undesirable,” he said, putting it mildly, “to believe a proposition when there is no ground whatever for supposing it is true.” Today he might have applied this to conspiracy theorists and “fake news”-evidence-deniers, but Russell applied this kind of empirical logic to social issues such as war and religion – he was an atheist, and long before Richard Dawkins and Christopher Hitchens he was writing controversial popular books such as *Why I am Not a Christian*. But whatever one’s spiritual inclination, the point about debating something logically is not *belief* but logical *structure*.

Everything I say is a lie.

Of course, we’re not all Vulcans like *Star Trek*’s Spock, so logic isn’t the last word either. But it’s certainly helpful, so let’s take a closer look at what goes into making argument, and how it leads to the rules of formal logic – especially symbolic and mathematical logic, in which Russell made major contributions.

Obvious does not equal correct

What’s the framework of logic? Is it art or is it science? Aristotle set the scene more than two thousand years ago, with classic arguments such as: “All men are mortal; Socrates is a man; therefore Socrates is mortal.” There are three categorical statements here; the first two are premises, from which the third follows – it’s a structure now known as a syllogism. The ancient Indians and Chinese also developed logical systems of thought. But modern, symbolic logic began to arise in the mid-19th century – and it had a great deal to do with the development of symbolic algebra, which was taking shape at the same.

This might seem surprising, given that the *X*s and *Y*s we take for granted today date from the seventeenth century. But nineteenth-century symbolic algebra was designed to tease out the structure *underneath* the symbols, by identifying and naming the “commutative law,” $X + Y = Y + X$, and so on. The idea was that these arithmetical laws might apply not just to numbers, but to anything with the same structure – including, perhaps, logical propositions.

For instance, Russell pointed out that if a statement seems obvious, it is too easy to assume it is correct – but if you can express it symbolically, you eliminate the apparent obviousness and get down to the logic of it.

So symbolic logic is about finding a way to encode clearly and concisely the logical structure of an argument or chain of reasoning. In his *Mysticism and Logic and other essays*, Russell expressed this idea by quoting Gottfried Leibniz, who had dreamed of a universal language for expressing the rules of reasoning in a manner similar to arithmetic. Then, said Leibniz, in any argument at all it would suffice for the disputants to “take their pens in their hands, sit down at their desks, and say ‘Let us calculate!’ ”

But how does one calculate reason and thought? It took two centuries to turn Leibniz’s dream into reality. The person who did it was the self-educated son of a poor cobbler from regional England – yet he helped pave the way for the digital revolution. His name was George Boole, and he gave us the Boolean logic that underpins not just thought but computing, too. The way he did it was deceptively simple.

Proposition precision

We make statements all the time, generally without worrying about how two propositions might be connected logically. To take a simple example, the weather is always a good icebreaker in social interactions, such as when we say: “Nice to see the sun shining today.” Boole’s objective was to make precise even such simple statements as this. For a start, he said, “the sun is shining” can be true or false. If it is true, then it is certain, so it has a probability of ***1***; if it is false it has a probability of ***0***. A reply such as, “let’s hope it’s a nice day on Saturday or we’ll have to postpone the barbecue” links two propositions, “Saturday is nice” and “the barbecue is postponed”. The logical connection between them is that one will be true and the other false.

For a more high-tech illustration of this idea, the latest car safety features include such helpful prompts as beeping if you inadvertently stray across the lines marking your lane. The technology requires cameras, sophisticated software and intricate circuitry, but the ultimate aim is to tell the car’s computer, “**If** the blinker is off **and** the car is crossing the line, **then** beep.” As Boole pointed out, connectives such as “if… then,” “and,” “not,” and “or” are key to the grammar of logic. But how to express it in symbolic language that a computer can read, or that humans can use to analyse arguments – that is the question!

Boole’s approach was to mimic the symbolism of algebra, using letters for different propositions, and the operators **+**, **–**, x and **=** for the logical operations ***either or***, ***not***, ***both and***, and ***is the same as***. He showed that generally these operators actually obeyed the same laws of algebra that his friend Augustus De Morgan had pioneered. After all, ***either X or Y*** is the same as ***either Y or X***, just as when $X + Y = Y + X$. It’s quite marvellous, really: these ancient, basic rules of arithmetic do actually encode the way the logical mind works.

Still, logic is not arithmetic. One of Boole’s axioms is $X + X = X$, because the left-hand-side says ***either X or X*** – in other words, just X. In contrast to this “Boolean algebra”, in ordinary algebra $X + X = X$ only if $X = 0$, so you can see why later logicians chose to replace **+** with a symbol such as $\vee$. Similarly, they replaced Boole’s x with $\wedge$, for Boole wrote ***both X and X*** as $X \times X = X$.

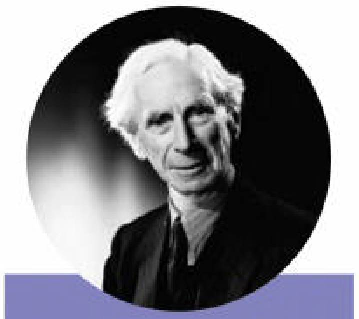
The symbol $\wedge$ is similar to the symbol $\cap$ for the intersection of two sets, just as $\vee$ is similar to $\cup$ for the union of two sets. You can see the connection between sets and logic when you consider the nuances of everyday speech. Boole pointed out that when you say something like “X or Y” do you mean ***either X is true or Y is true***, or ***either X is true or Y is true or both are true***, or ***X and Y are both true***? It turns out that these different meanings can be encoded in the Venn diagrams used in set theory (see previous page).

German mathematician Gottlob Frege first put the concepts used in logic into modern set theory form in the 1880s. Russell independently developed a similar approach around 1900, and today he and Frege are considered the founders of modern logic.

When logic gets complicated

Even when its operations are set out clearly like this, logic can seem bizarre rather than, well, logical. That’s because logic is not concerned with what you say but simply whether or not a conclusion follows logically from its premises. It can be hard to get one’s head around the idea that an argument can be valid even if some of its premises are false. Let’s unpick this a little.

We have no trouble saying things such as “if the sun is shining we’ll go ahead with the barbecue”. It’s a subtly different way of framing our earlier either-or barbecue proposition. Boole symbolised such statements as ***If Y is true, then X is true*** where in this case Y is the proposition “the sun is shining” and X is the proposition “the



> **“Mathematics is capable of an artistic excellence as great as that of any music, perhaps greater … it constructs an ideal world where everything is perfect and yet true”**
>
> Bertrand Russell

If pigs fly, then I’m a monkey’s uncle

If Y then X is true even if Y and X are false, prove “If 2+2 = 5, you are the pope”

If 2+2 = 5,
then since 2+2 = 4
5 = 4.
5-3 =2 and 4-3 = 1 so
2 = 1.
The pope and I make two, so the pope and I are one.

HULTON DEUTSCH/GETTY IMAGES

barbecue goes ahead" – and if both these things are true, then obviously so is our statement. But we're also familiar with sayings such as "If pigs can fly then I'm a monkey's uncle." This, too, is a proposition of the form ***if Y then X*** – and it is a true statement, *even though* neither ***Y*** nor ***X*** is true.

In fact, the statement is true precisely *because* neither of its propositions is true. If you're confused, take heart. There's a famous story about Russell's attempt to explain this during a seminar at Cambridge. In response, the mathematician G. H. Hardy threw out a challenge: if you can say "If Y, then X is true even if Y and X are false", then prove that "If 2+2 = 5, you are the pope" is true. Quick as a flash Russell responded along the following lines:

If 2+2 = 5, then since 2+2 also equals 4 we must have 5 = 4.

Subtract 3 from both sides of this last equation, to get 2 = 1.

But since the pope and I also make two, we have just proved that the pope and I are one.

and

X	Y	XY
0	0	0
0	1	0
1	0	0
1	1	1

or

X	Y	X+Y
0	0	0
0	1	1
1	0	1
1	1	1

if... then

X	Y	X→Y
0	0	1
0	1	1
1	0	0
1	1	1

iff

X	Y	X↔Y
0	0	1
0	1	0
1	0	0
1	1	1

It's a perfectly logical argument, which goes to show you can prove anything if you accept a false proposition as true!

More seriously, showing that ***if Y then X*** is true even if ***Y*** and ***X*** are false comes out in the rules of logic. And this is the important thing: these rules do have to be defined, just as the laws of mathematics have to be defined. The Venn diagrams are foundational, but they are not enough to say more complicated things than ***either X or Y***, ***both X and Y*** and so on. So the rules for ***if Y then X*** and other more complicated arguments need to be defined according to the "propositional calculus" that arose following Boole's work.

This "calculus" is often expressed in terms of "truth tables," where a statement such as ***if Y then X*** is evaluated depending on the truth (represented by ***1***) or falsity (represented by ***0***) of its propositions (as above). Lewis Carroll – aka Oxford mathematician Charles Dodgson, and author of *Alice's Adventures in Wonderland* – was one of the pioneers in writing out logical statements in tabular or diagrammatic form. John Venn – he of the eponymous circles – was another. But as I've implied, the language of set theory also enables the content of truth tables and other logical diagrams to be expressed purely symbolically.

Mathematical proofs obey the same logical rules of reasoning. Russell was so entranced by this connection between logic and maths that he set out to deduce, entirely from the axioms of set theory and the rules of logic, the fundamentals of mathematics itself.

The result was the remarkable three-volume *Principia Mathematica* (*PM* for short), written with his former Cambridge professor Alfred North Whitehead. Russell said he was indebted to Italian mathematician Giuseppe Peano, whom he'd met at an International Congress of Philosophy in 1900. Russell was struck by the fact that Peano "was always more precise than anyone else, and that he invariably got the better of any argument… I decided that this must be owing to his mathematical logic".

In 1931, however, the Austrian mathematician Kurt Gödel would throw a proverbial spanner right into the heart of Russell and Whitehead's attempt to deduce maths from logic. He showed that in *PM* – or any other axiomatic system about "number theory" (which studies the set of integers and their arithmetic properties) – it is simply not possible to prove *every* statement. Russell (and Spock) must have been devastated: logic was not the last word after all – at least, not when it came to deriving mathematics.

Nevertheless, in the process of writing *PM*, the first volume of which appeared in 1910, Russell had made and published many new results in mathematical logic. The most famous of these is now known as "Russell's paradox." It threw set theorists into a spin –and especially Frege, who was about to publish on the subject when he received Russell's letter about his discovery. The paradox is often presented as a story about a small village with one barber, who shaves everyone who needs

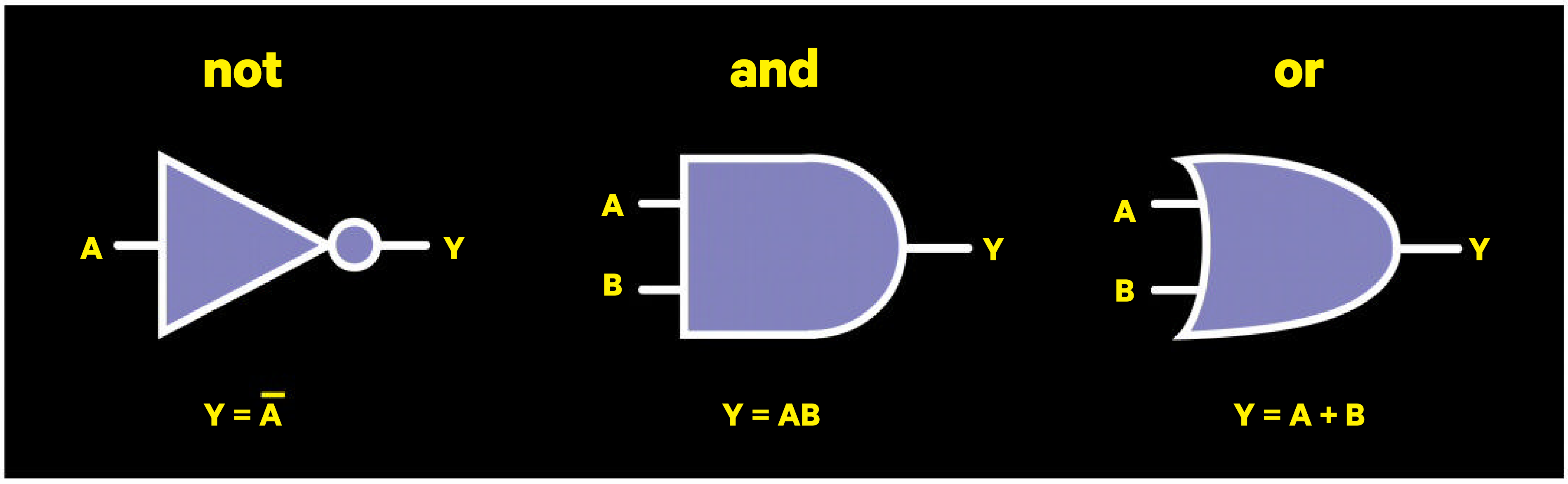
Does a catalogue of catalogues list itself?

One barber shaves everyone who needs shaving, except those who shave themselves. Who shaves the barber?

shaving – except, of course, those who shave themselves. *But who shaves the barber*? It sounds like a parlour game – but its implications are profound.

In the set theory language that Russell used, what this suggests is that contradictions arise when you bring in *self-reference*, by talking about "the set of all sets that are not members of themselves" (or the barber who shaves "all those who don't shave themselves"). For example, a forest, a set of trees, is not a tree, so it is not a member of itself. (By contrast, a catalogue of catalogues presumably lists itself, so it *is* a member of itself.)

But when you take the set of *all* sets that don't contain themselves – let's call it **φ** – you have a problem: where does **φ** itself fit in? It can't be a member of itself, because that is a contradiction: **φ** contains only those sets that *don't* contain themselves; similarly, if it is a member, then it shouldn't be – just as the barber belongs neither to the set of people who shave themselves nor to the set of people that don't.



The barber analogy was suggested to Russell in response to his paradox, although he felt it was too simplistic. Russell called propositions with a single verb "atomic" – Boole's "the sun is shining" is an example – so you can see that both logic and set theory have a lot to do with language. In this case, the problem was with the word **all** – the set of *all* sets that do not contain themselves, or the barber who shaves *all* those who do not shave themselves. Russell pointed out the similarity to the "liar paradox" connected with the semi-mythological ancient Cretan Epimenides, who supposedly said, "All Cretans are liars." If he's telling the truth, then he's a liar – and vice versa.

Russell's solution was his "theory of types". You can say, "all atomic propositions are either true or false" – but the statement itself is not an atomic proposition. It is a statement, a proposition, *about* atomic propositions, and so the set of such statements belongs to a different (higher order) degree of proposition than does the set of atomic propositions. Each time you want to say something about a set (or set of sets, or….), that something is not part of the set, so you avoid the contradictions that arise from self-reference, when sets both are and are not members of themselves.

Resolving the paradox

Russell, however, was not one to ignore evidence in order to keep to his "comforting convictions." He knew that his own resolution of the liar-barber paradox hadn't pleased all the logicians, including his famous student Ludwig Wittgenstein. His protégé George Spencer-Brown didn't like it either, and developed a startling alternative in *Laws of Form* (1969), his remarkable re-imagining of formal logic. To his relief, his mentor was delighted: Russell had always thought his theory of types was just a stopgap – and it was thanks to Russell's urging that Spencer-Brown's publisher took on *Laws of Form*.

George Boole's principles set a structure for logical thought that forms the basis of binary and complex computing.

DEA/BIBLIOTECA AMBROSIANA/GETTY IMAGES

Spencer-Brown's "resolution" essentially said that the paradoxes of self-reference were not so bad. They're there in physics, because we're both part of the universe *and* making theories about it; and they're there in mathematics, when we solve equations such as $x^2 = -1$, which is self-referential when you rewrite it as $x = -1/x$. Yet mathematicians got around this problem by broadening the category of number to include not just positive, negative or zero numbers, but imaginary ones as well. So, said Spencer-Brown, you can get around the paradoxes of logic and set theory by broadening Boolean algebra, so that it includes not just true or false (or meaningless) statements but also "imaginary" or recursive ones.

There's a whole lot more to *Laws of Form*, but what fascinates me is the kind of creative thinking that

Russell's paradox – and all the associated pioneering work in logic and symbolic algebra – inspired.

In spite of Spencer-Brown's bold take on self-reference, others *have* actually found inspiration in Russell's theory of types – for example in the software for "proof assistants". Russell and Whitehead had expressed the rules of mathematics in a purely symbolic, set-theoretic and logical way, which meant that in theory mathematical proofs could be checked mechanically. As Cornell professor Robert Constable has noted, today's proof assistants are helping mathematicians to realise *PM*'s dream.

So *PM* has had a huge impact on the development of logic and mathematics, even making its influence felt in computer science. At the time, though, it was so esoteric that the authors had to contribute to the cost of its publication. As Russell wryly noted: "We thus earned -£50 each for ten years' work. This beats *Paradise Lost*."

From Aristotle to AI

Boole, too, has been hugely influential. In 1938, an American MIT masters student, Claude Shannon, published a thesis showing how Boolean logic could be represented as electronic circuits. First there are switches (or voltage regulators), where ***on*** (or "high" voltage) represents ***1***, and ***off*** (or "low" voltage) represents ***0***. Then you can connect two switches in series to represent ***X and Y are both true***, while connecting them in parallel represents ***X or Y is true*** – with more complicated circuits representing more complicated propositions. The electronic digital revolution was on its way; all it needed was for someone to invent a computer!

One of the first steps towards this goal was the thought-experiment that became known as a "Turing machine". While Shannon cited Boole, the British mathematician Alan Turing took his lead from Russell (and Gödel, who'd taken *his* lead from *PM*). Turing is famous for his use of logic in breaking the German Enigma code during the Second World War – and for the tragedy of his 1954 suicide, apparently due to the homophobia that saw him arrested in 1952. He was born in June 1912, so we can celebrate his 110th birthday along with Russell's 150th.

While Gödel showed that not all theorems are *provable*, in 1936 Turing showed that not all mathematical quantities are *computable*. He defined real numbers as "computable" if there is an algorithm that generates them. For instance, you might think that π is not computable, but it can be generated by algorithms such as

$$\pi/4 = 1 - 1/3 + 1/5 - 1/7 + 1/9 - \dots$$

which comes from the series for $\tan^{-1}x$. What Turing discovered, though, was that if you tried to test for computability in advance, you ended up with yet another analogue of the liar or barber paradox! In other words, he showed that it was not possible, even for a computer, to compute everything. It had to do with the problem of self-reference again – just as we had with Russell's paradox and sets containing themselves, and with Gödel's axiomatic systems, such as *PM*, trying to prove themselves complete.

It's intriguing, because the problem of self-reference also comes up in the most mysterious phenomenon of all, human consciousness, which not only perceives the outside world but itself, too. Turing was fascinated by the idea that our minds work like computers – not in their hardware but in their reliance on algorithms.

In 1950 he kick-started the field of artificial intelligence (AI) when he proposed his famous take on the Victorian "imitation game," now known as the "Turing test". The idea was for the player to pose various questions to an unseen human and a computer, who would reply in writing so as not to give the game away. If the player couldn't tell which was which, then the computer was deemed to be "thinking".

Machines are getting "smarter" all the time, although none has passed the Turing test. But the lead scientist at Amazon's Alexa program, Rohit Prasad, believes that AI is now so advanced and so ubiquitous in our smart technology that the Turing test is no longer a useful benchmark – and he's not alone.

Away from high-tech labs, philosophers and mathematicians, too, are debating the relationship between intelligence and machines (or algorithms) – and the reach of Gödel's and Turing's results on provability, computability, and AI.

Perhaps the human mind can do more than a computer ever could – and perhaps human creativity, with its insight and its human error, makes Gödel's theorem irrelevant: we make mistakes anyway, so does the "incompleteness" of maths really matter? Is human creativity more than computability, or a behaviourist analysis such as the Turing test?

And Russell's own philosophical work on a theory of mind and matter called "neutral monism" has been having renewed impact on the study of consciousness, thanks initially to Australian philosopher David Chalmers.

So on Russell's 150th birthday I think it's good to pause amid the excitement of ever-advancing technology, and remember the philosophers and mathematicians, past and present, who have not only helped make it all possible, but who have also stopped to ask questions about how we think and who we are.

PICTURES FROM HISTORY/GETTY IMAGES

> **"We do not wish to penalise the machine for its inability to shine in beauty competitions, nor to penalise a man for losing in a race against an aeroplane"**
>
> Alan Turing

ROBYN ARIANRHOD is an affiliate in mathematics at Monash. Her last story, on algebra, appeared in Issue 92.

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Engineer this: *Inception* style, an other-dimension Shanghai hovers above the ‘real’ city – or is it the other way around? When ours becomes a quantum world, how will engineers respond to particle-level measurements with a side-serving of uncertainty? Read more on page 100.

JACKAL PAN / GETTY IMAGES

ZEITGEIST

SCIENCE MEETS LIFE

100
QUANTUM ENGINEERING
Why tomorrow's engineers need the science fiction of today

104
SNAGS UNTANGLED
Going where few dare: inside the sausage sandwich

108
YOUR QUESTIONS ANSWERED
Why are heavenly spheres not cubes? Is Option 3 always the best? And what's the wagon-wheel effect?

112
PUZZLES
Science-inspired brain bogglers

114
PROFILE
Mammalogist David Hamilton

ENGINEERS ARE ENCOUNTERING THE EDGES OF REALITY

A world ruled by particle-level measurement with a side-order of uncertainty is going to present future engineers with some pretty serious challenges, writes **JAMIE SEIDEL**.

There's something seriously wrong with reality. It's dysfunctional. And that has serious implications for engineering our future. The smallest things are causing the biggest problems.

Two seemingly incompatible universes have collided. "The world we experience is driven by determinism," says Flinders University spectrum security specialist Professor Samuel Drake. "We observe things. We measure things. From that, we know what outcome to expect. And once we know what's happening, we can engineer faster cars, put satellites in orbit, and build better computers."

But our understanding has limits.

"Things that happen in quantum mechanics have raised the prospect that there is no such thing as determinism," says Drake. "Even if I know something precisely, I can't predict the outcome."

What this means is that the world's engineers are in the awkward position of grappling with uncertainty, and it's having real-world implications – in computing, in nanotechnology and with sensors. Our understanding of how things work has struck a hurdle.

Albert Einstein first crashed up against the problem in the early 1900s. His all-encompassing theory of general relativity encountered one arena it could not explain: quantum mechanics.

Both concepts effectively explain the different levels at which they operate. More than a century of research and testing have strengthened the validity of both. But all attempts to rationalise the two worlds into one over-arching, universal set of rules have failed.

That's now a real problem. Modern technology needs to operate between both scales – at the edge of reality.

"It's getting to the point where a modern engineer needs to understand quantum mechanics," Drake says. "Everything is getting that small and that accurate."

So how can engineers solve the practical problems of the world we live in at the point where two sets of fundamental rules refuse to interact?

At an immediate and practical level, many of today's engineers are hardly bothered by quantum mechanics, says New South Wales-based mechanical engineer Michael West, a practitioner with more than two decades' experience.

"It really depends on where the engineer works," he says. "If you look at the term engineering simply, it describes the application of physics and maths in real problems.

"There's a large number of engineers who, in the [work of] monitoring their project, if they have to measure anything, relative to quantum level usually [the increments] are quite large. We're talking millimetres to metres to kilometres. And that's as far as they need to go.

"So, when you're talking about quantum level, in my mind it refers to people

VIVID CAFE/SHUTTESRSTOCK

KARIBE KASSAM/SHUTTERSTOCK

working in engineering who may need to measure things at that level. Many of the problems that we have, the tolerance is crude compared to the quantum level."

CONTENDING WITH CHAOS

Quantum mechanics was once a thought experiment confined to small groups of theoretical physicists – nothing that impacted the "real" world.

But the world has moved on. Microchips are now a thing of the past, replaced by quantum computers and sensors. This means that building an interface with the quantum realm is now a practical necessity.

"Engineering has always relied on precision and accuracy," says Drake. "After all, it always worked. But reality as we know it has its limits."

Next-generation minerals exploration is using magnetic and gravitational fields to find mineral ore at ever-greater depths. And such sensor technology must detect changes at subatomic (quantum) levels.

Then there are the emerging fields of quantum computing, radar and encryption, not to mention GPS alternatives such as quantum clocks, accelerometers and compasses.

That's where normal rules don't apply. "Devices have become so small that we are seeing what Einstein called 'spooky action at a distance' happen," says Drake. "The Schrödinger's cat phenomena (where two separated particles both react when one experiences an interaction) is appearing in our equipment."

Samuel Drake sees the future of engineering intersecting with physics and quantum – creating solutions from technologies currently in the realm of science-fiction.

In essence, measurements are becoming complicated. Results are less certain.

"Determinism tells us that if we take precise enough measurements, reliable predictions are possible," Drake says. "Quantum physics says 'no' – things are inherently uncertain, no matter how precisely you measure them."

West's professional engineering experience echoes the determinism/prediction nexus.

"One thing that I've learnt and I've always kept in mind is that an engineer can only approximate," he says. "[Thinking about] fluid mechanics: back in the day, people used testing and empirical methods to work up datasets, and then they put one-off equations to those so that people could work out the behaviour of water in channels and pipes.

"It wasn't until later that people took a theoretical approach and put some mathematical equations to that, then those equations behaved as the fluid does in practice – so we could model fluids using that theory. The theory is applicable to the system that we're working on, and the tolerance is what we're willing to accept in error."

Reliable predictability is one thing. The concept of inherent unpredictability is not something engineering's pragmatic mindset is tuned to accept, and the problem is amplified when computers and machine learning gets involved.

"Uncertainty can be useful," says Drake. "It guides human behaviour, so we don't become too reliant on something. We comprehend mistakes and false alarms. But algorithms operate without context, And uncertainty causes them to break down."

And quantum reality is built on uncertainty.

WHEN REALITY GETS DIVORCED

Quantum mechanics and Einstein's theory of general relativity refuse to agree. Neither theory can explain how the whole universe works. Both become nonsensical when applied to the opposite end of the scale. But evidence supporting the different theories just keeps piling up.

Every advance in astronomy – such as gravitational waves – has backed Einstein. And quantum mechanics still can't explain gravity.

For its part, general relativity can't explain interactions at the subatomic level. But the Large Hadron Collider sees quantum behaviour every time it smashes an atom.

So, says Professor Drake, it may have to be engineers that build a bridge for the two trains of thought to cross that gap.

Einstein's theory of relativity explains the universe in above-atom scales – such as footballs, planets and galaxies. Quantum mechanics deals with the subatomic – nuclei, electrons and quarks. Most of the time, both universes get along quite well without each other. Now we need these fundamentally different forces of nature to

interact.

But it's a marriage made in philosophical hell.

Is the building block of the universe a wave – where everything is smooth and connected? In this model things are deterministic; every cause matches a specific effect.

Or is it a particle – an individual quantum 'dice' where the sum of their rolls establishes a probabilistic reality?

That distinction becomes essential when you're trying to measure gravity, and we definitely want to do that. It shapes the universe, yet it's far weaker than the other forces of nature, such as magnetism.

How can something so weak be so strong? This paradox is the reason why gravity must be measured at a scale measured in fractions of an atom.

Here uncertainty lies.

What are we looking at? What is it doing? What is it telling us? Is it deterministic? Or probabilistic? Or something else?

The answer could open up new possibilities for mining, archaeology – and submarine hunting.

THE QUANTUM OF UNDERSTANDING

How much physics does a pilot need to know? How much mechanical knowledge does a driver need? A clear answer needs fewer words than you'd imagine.

"Being a professional is quite different from being a researcher or developer," says Drake. "They experience it. They train for it. They are a user who lives it."

But engineers, who've up to now been able to work and calculate in a deterministic world, will in the future need to build bridges to the quantum world.

"They don't need to grapple with multi-universe or string theories," says Drake. "But they do need to understand the Schrödinger equation – the way particles and electrons work."

This understanding will empower engineers to do what people do best: apply context.

"That's where we need the human in the loop," says Drake. "We need to understand what uncertain results may be telling us. Algorithms can't do that."

At face value this sounds reasonable, but context is proving to be a rigid boundary between humans and machines.

Machine-learning algorithms produce fantastic results with the data they are trained on. But give them a slightly different dataset, Drake says, "and the machine says 'I don't know what this is – I've never seen it before'. They can't contextualise it."

Consider this: now, in what is still a pre-quantum world, we can trust sensors to give us a result.

But, at the smallest scales, we can't trust algorithms to determine what that result actually is. Are those minute gravity fluctuations deterministic measurements revealing a submarine in the depths or a new copper deposit? Or is it a random roll of the quantum dice?

"It does tell you implicitly that there is uncertainty even in the physical world," says Drake.

"Is there some link between the uncertainty principle in an electron and our human brain's ability to understand that there will always be uncertainty? How do you code that?"

That's the challenge engineers and developers are starting to face, and one that will grow in the future.

For now, West is able to steer around quantum principles in his regular work, but he's aware of the coming storm.

"Is going to the quantum level going to give me any more information that's usable to the objectives of my current projects?" he asks. "In day-to-day practice, I would say no.

"However, I think that it's technology and application dependent. I encounter jobs that use new technologies and methods to satisfy a practical application.

"Whether it's a structure or a fluid mechanics system, for example, currently the technology gets worked into a model that can be practically explained. So will classical theory achieve what I need to know? The answer will be yes. But we're talking about things we can see – moving fluid from A to B, the consumption of energy in doing that work, and getting a system to be as efficient as we can.

"But what if I'm going to invent something [using] technology that's only known in science fiction at the moment? To make that a reality, I may very well need something more than classical engineering principles."

"We need engineering students to study physics and high-level maths because that is the way engineering is going," says Drake.

"They must grapple with the essential idea of deterministic versus probabilistic being an inherent part of nature. As things get smaller and smaller, this is increasingly going to become their reality."

> "DEVICES HAVE BECOME SO SMALL THAT WE ARE SEEING WHAT EINSTEIN CALLED 'SPOOKY ACTION AT A DISTANCE' HAPPEN"

JAMIE SEIDEL is an Adelaide-based writer. His last story – on laughter in animals – appeared in Issue 94.

The science of the sausage sizzle

The sanger sandwich is a staple of school fairs, sports days and shopping for hardware. But have you ever wondered what's actually in the sausage and bread that's part of our culinary heritage?

Whether you're joining the grand tradition of the democracy sausage on election day, or chucking a couple of bucks to the local scout group outside a hardware store, the sausage (or veggie equivalent) and white bread partnership of a sausage sizzle is hard to resist.

But what's actually in a sausage? What's allowed to call itself a sausage? And does pricking them while barbecuing really make them healthier – or does it just make them taste worse?

What about the bread the sausage sits in? How does it stay fresh for so long?

We're going to do what you're never supposed to do: see how the sausage is made.

What's in a sausage?

Lots of people are concerned about ambiguous meat of any description – but Australia has some of the strictest food regulations in the world. Food Standards Australia and New Zealand has rules about what's allowed to call itself a sausage.

A sausage must be at least 50% meat – or 500 grams per kilogram, to be precise. The other 50% can be whatever improves the flavour of the sausage. Fats, starches like rice or wheat flour, salts, various flavours and preservatives are all common.

Manufacturers also need to specify the meat content of a sausage. The packaging, or the butcher, should always be able to tell you about the amount of meat in the snag – even in the cheapest ones, it often goes well above that bottom line to numbers around 75%.

But there's an added complication. That meat content doesn't have to be lean: in fact, it can be 50% fat itself. So theoretically, the sausage you buy could be only half meat, half of which is fat.

Manufacturers don't need to specify how much fat is in the meaty part of their sausage, but they do have to explain how much fat is in the sausage in total. So you can get a read of the fattiness of a sausage when you buy it, too.

If you're squeamish about eating other bits of the animal, you don't need to worry too much in Australia. Anything that has offal (things like brain, heart, kidney, liver,

TIM MACPHERSON/GETTYIMAGES

tongue or tripe) has to label itself as such. So you're not going to accidentally eat brains in a sausage – you'll get a warning on the label.

What's in the casing?

The sausage casing is less regulated, but it usually depends on a protein called collagen. This is an extremely common substance – it's the most abundant protein in mammals.

Collagen proteins are long, fibrous molecules, kind of like tiny ropes – and they are very useful connective tissue. Collagen provides a lot of the structure in our bodies.

The old-fashioned way to make sausage casings is to use animal intestines, which are rich in collagen. A newer method is to use purified collagen itself, which is usually taken from animal hides.

What's in plain white bread?

Assuming you're not involved in sourdough wizardry, bread is easy to make. It needs flour, yeast, and water. It usually also has salt, sugar or oil.

The white bread you get in supermarkets is no different: the starch and the yeast are the two key ingredients. There might also be some mineral or vitamin additives, and often things called "emulsifiers". These are chemicals that mix oily stuff and watery stuff together. Lecithin – a molecule found in egg yolks and soy beans, among other things – is a really common emulsifier.

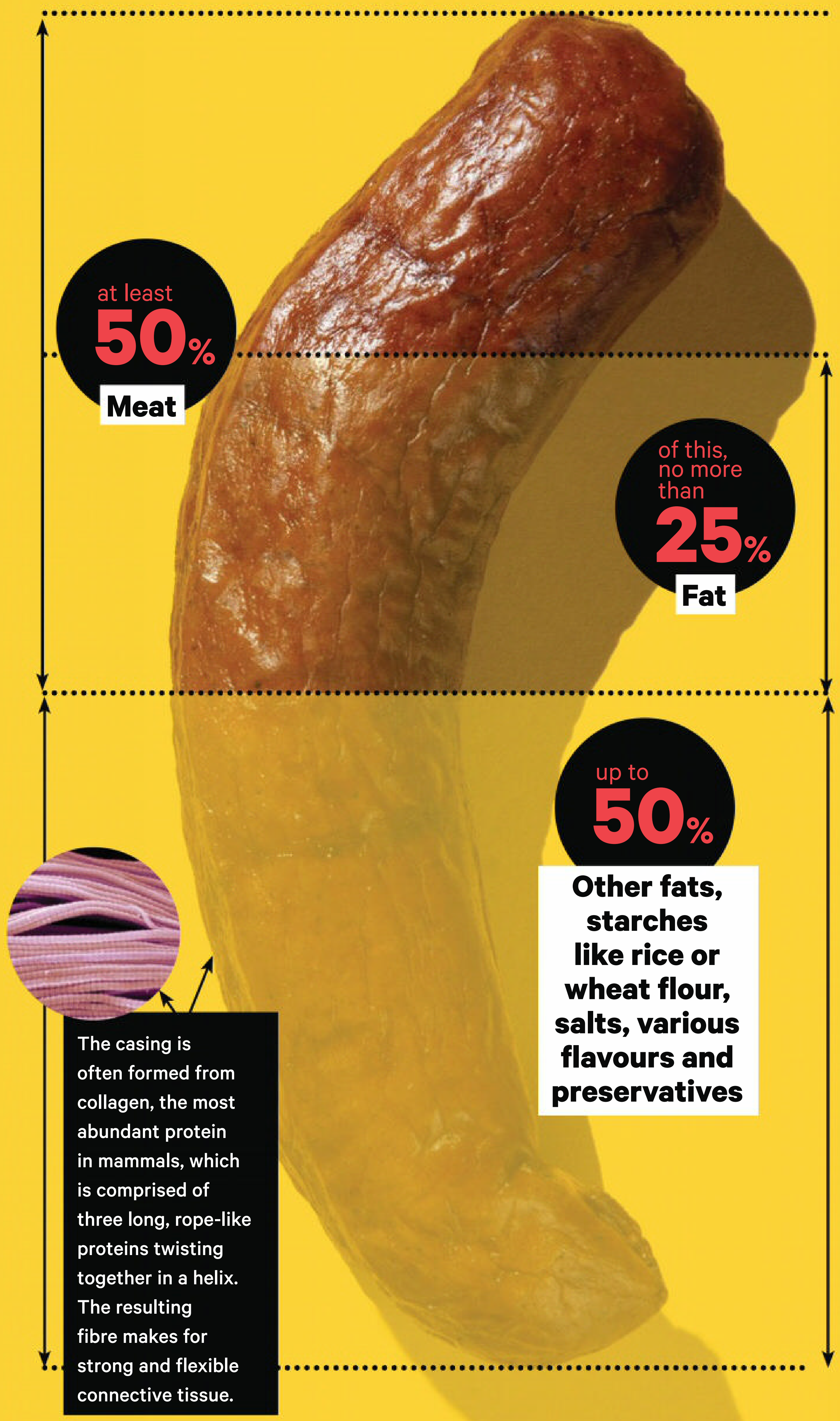
If it's all the same stuff as homemade bread, what makes packaged bread last?

I once left a packet of white supermarket bread on top of my fridge, to see how long it would take to go mouldy. After 29 days (well past the use-by date), one of my flatmates noticed the bag and asked me why it was there. Shortly after that, due to circumstances beyond my control, the experiment was terminated.

So I still don't know how long you can get supermarket bread to last. You are welcome to try your own experiment: I urge you not to eat it, or to tell any of your co-inhabitants about it. While you watch the bread, consider the ingredients in it that are stopping it from getting mouldy.

If you're trying to keep food fresh, what you're really doing is killing things that live in it – bacteria, fungus, and other microbes.

There's a variety of ways you can do this. Heating the bread to bake it is the most obvious, but manufacturers usually use one or two other tactics, as well.


at least
50%
Meat
of this, no more than
25%
Fat
up to
50%
Other fats, starches like rice or wheat flour, salts, various flavours and preservatives

The casing is often formed from collagen, the most abundant protein in mammals, which is comprised of three long, rope-like proteins twisting together in a helix. The resulting fibre makes for strong and flexible connective tissue.

> "Much like us, microbes don't like drinking straight vinegar – the lower the pH, the fewer that survive. This is why you see vinegar on a lot of bread package labels."

FIBRES: STEVE GSCHMEISSNER. SAUSAGE: MAKING_ULTIMATE/GETTY IMAGES

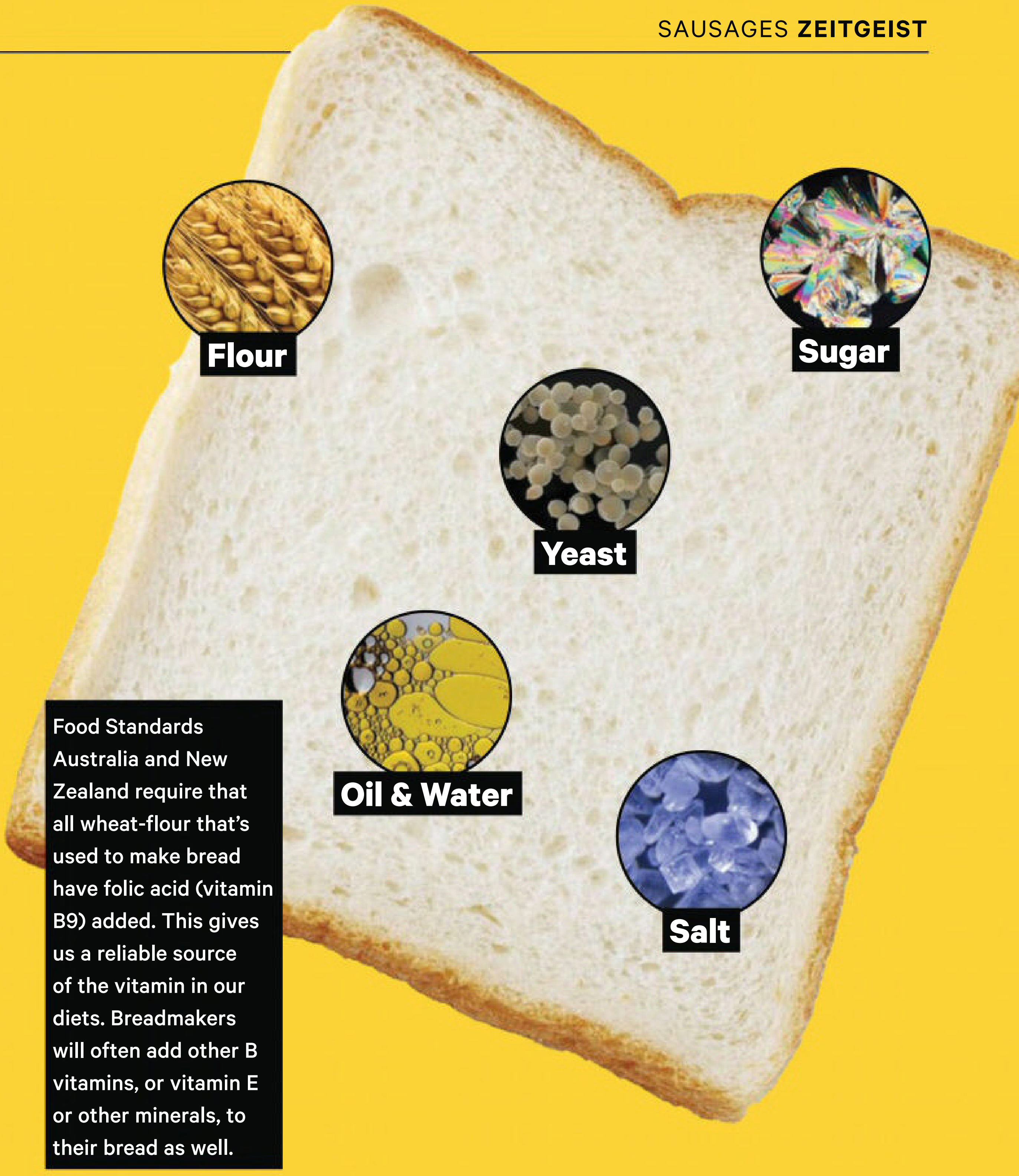
A common one is to make the bread acidic: that is, treat it with vinegar. Much like us, microbes don't like drinking straight vinegar – the lower the pH, the fewer that survive. This is why you see vinegar on a lot of bread package labels.

Another option is to suffocate the tiny creatures. Bread bags are often filled with carbon dioxide or pure nitrogen, in order to exclude the oxygen that microbes need to respire. Sometimes, manufacturers will add packets that absorb oxygen to bread bags as well, to further lower the breathability – this is the logic behind plastic packaging of many foods.

The most exciting thing you can do to preserve bread is irradiation. During processing, the food is deliberately exposed to gamma rays or powerful X-rays. These rays have enough energy to ionise things: that is, strip electrons away from their atoms.

This murders the microbes that are hanging out in the bread. But the radiation isn't powerful enough to make the food radioactive. It's similar to a microwave – the gamma rays change a physical property of the bread (and the microbes), but they don't leave anything behind. The process has been extensively tested, and it's as safe as any other preservation technique.

Also, at the moment, bread irradiation isn't permitted in Australia. A few other foods can be irradiated through: herbs, spices, and some tropical fruits.



Food Standards Australia and New Zealand require that all wheat-flour that's used to make bread have folic acid (vitamin B9) added. This gives us a reliable source of the vitamin in our diets. Breadmakers will often add other B vitamins, or vitamin E or other minerals, to their bread as well.

BREAD: IMAGENAVI/GETTY IMAGES. INGREDIENTS: ITHINKSKY, BAAC3NES, NNEHRING, DAVID SPEARS, ROSENDO SERRANO VALERA

Cooking the bugs (and flavour?) out

Barbecuing the sausage is doing the same job as irradiating (or vinegarising) the bread. You have to make the sausage uninhabitable to microbes – this time, with temperature.

Debate rages as to whether you should prick your sausages before cooking, or leave them be. There's a rumour that pricking the sausage allows the fat to melt and leak out, making it healthier – but I haven't found any scientific backing to support this.

But pricking can prevent the sausage from exploding. If there's enough water in the sausage that's boiling and turning into a gas, it will expand and break the skin. The prick gives the sausage a bit of an outlet.

Lots of people think that puncturing or not puncturing changes the flavour of the sausage. I am completely unqualified to comment on this, but will gladly plot an experiment to test it on request.

The Onion Conundrum

A few years ago, Bunnings made headlines by releasing a controversial sausage sizzle edict: the onion should go below the sausage, not above. This, apparently, reduces the tripping hazard.

Many people were furious about this rule. How likely was it, really, that someone was going to trip over an onion ring?

But, as someone who once had to write a risk assessment for a thought experiment, I feel for the Bunnings staff. The thing about safety regulations is that once a hazard has occurred to you, you don't really have a justification for not addressing it. It becomes unethical to ignore it.

Plus, there have in fact been reports of one or two people who've slipped on onions at sausage sizzles. This broad public health restriction probably will avoid a few injuries – and it's way less disruptive than capacity limits.

So I understand the bottom-onion rule. But given a choice, I personally am willing to risk keeping my onions on the top. ⊙

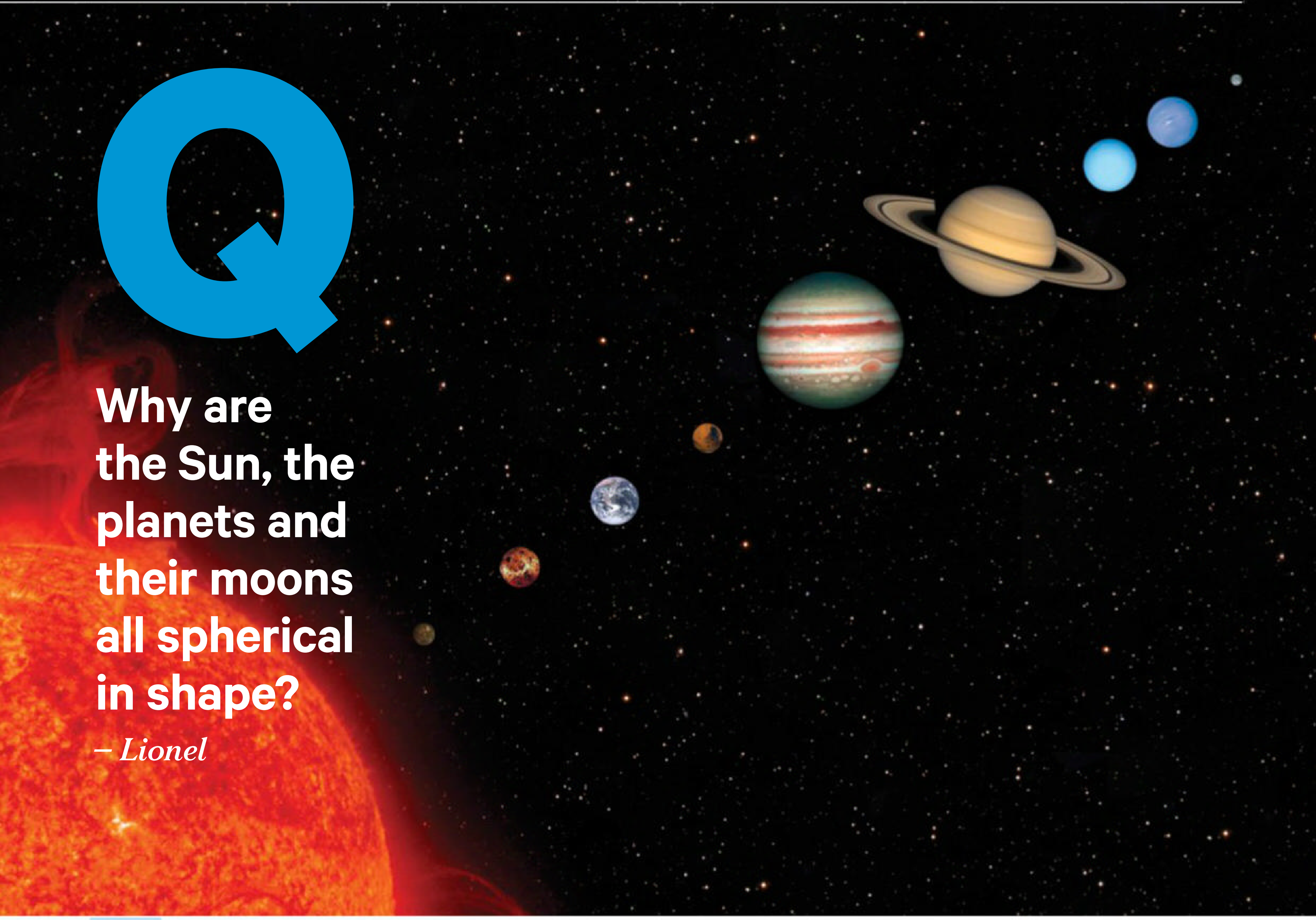
ELLEN PHIDDIAN is a chemistry graduate and journalist at *Cosmos*.

Hear *Cosmos* journalists explain all of life's big and small questions on our new weekly podcast: *Huh? Science Explained*

LiSTNR HUH? SCIENCE EXPLAINED COSMOS

Q&A

Cosmos has asked people from across Australia to send us their science stumpers. This issue, just some of the highlights as our journalists tackle heavenly spheres, game-show neurology and the wagon-wheel effect.



Q

Why are the Sun, the planets and their moons all spherical in shape?

– Lionel

A

Wait, what? The Earth is actually flat, haven't you heard?

Kidding! We've actually known that the Earth is round for at least 2000 years, thanks to the ancient Greeks. In fact, the vast majority of objects in our solar system are spherical, from the Sun to planets to moons.

So why are planets spherical? Why don't we live on a cylindrical or cube-shaped planet?

The main culprit is gravity. Every object in the universe with mass exerts a gravitational pull, which tugs towards the object's centre of mass.

For a planet, everything is pulled towards its centre – that's why things hit the ground when you drop them, and why you land back on Earth when you jump. When the Earth formed 4.6 billion years ago, it was composed of molten material that gravity pulled into a spherical shape, which solidified as the planet cooled.

Some objects in the solar system are too small to be forced into spherical shapes – Mars' moons, for example, are potato-shaped, and asteroids are mostly irregular.

But not even the planets are perfect. Their shapes are scientifically described as "oblate spheroids", because they all bulge slightly around the middle (like a mandarin or a semi-inflated soccer ball).

This means that if you walked around the Earth from the North Pole to the South Pole and back, you'd travel about 39,931 kilometres. But if you walked around the equator, you'd travel 40,070 kilometres – pretty close to a perfect sphere, but not quite.

Saturn is the bulgiest of all the planets, being more than 10% thicker around the equator than around the poles.

This bulge is a result of rotation. While gravity tries to render planets spherical, the speed of their rotation tries to squash them. The faster a planet spins, the less round it is. Think of a merry-go-round – when it's whirling around quickly, it's hard to stay on at the edges, because centrifugal force is pushing all the outermost mass away. Translate this concept to 3D, and it's what makes a planet's equator bulge.

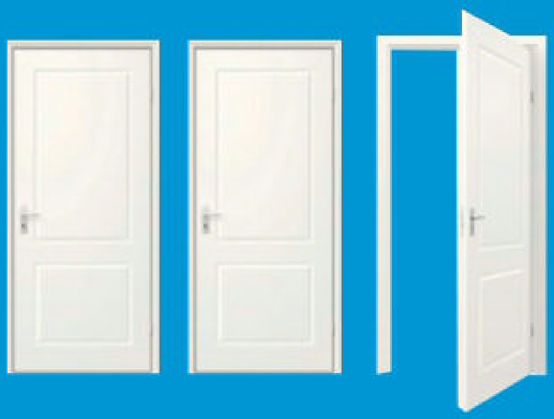
Since the planets rotate at different rates, they're all different shapes. Saturn is the most non-spherical – squashed – planet because it's spinning fastest, while the Sun, with its immense gravity and very slow rotation, is almost perfectly round. It really is a battle between gravity and rotation.

(To a lesser degree, the gravitational pull of other objects also makes a difference – for example, the Sun and the Moon alter the Earth's shape, but only a little.)

Anyway, it's pretty handy that the planets are spheres. If they were tetrahedrons or toruses or pentagonal prisms, it would be much trickier to make a solar system model…

Lauren Fuge

STEVE ALLEN / GETTY IMAGES



Q

In the US there is a program called *Wheel of Fortune*. The winner gets to pick from three categories for a prize. I estimate the third choice is chosen about 85% of the time, the second choice 10%, and the first choice 5%. What is it about our brains that causes this phenomenon?

– Richard

A

Well, it's complicated – and unsurprisingly, the body of scientific literature on human decision-making is vast. To help answer this question, I contacted Carolyn Semmler, an associate professor in the School of Psychology and leader of the Applied Cognition and Experimental Psychology (ACEP) research group at the University of Adelaide.

"When we're faced with a decision, we like to evaluate the supporting evidence for each option," says Semmler.

"As we accumulate more evidence in favour of a particular option, once it reaches that threshold boundary, then we make the decision."

But of course, we don't usually have perfect evidence to rely on – especially in a context like a game show, where we're being asked to make quick decisions under the gaze of a large audience.

"A lot of economic decision-making models really assume that you've got all the time in the world and you need all these complex calculations in your head," says Semmler.

"In reality, we can't do that – so we in fact have presumably developed these really efficient and quick ways of making decisions."

Psychologists think that such "fast and frugal" decision-making is based on a small number of "cues" that we've learned over time, that tend to help us reach a correct decision.

Why might the third category be popular?

What might be the cues, or factors, that make the third option more popular on *Wheel of Fortune*?

Richard wrote that he estimated the third option is chosen 85% of the time. In the name of independent replication, I spent an hour watching the category selection segment for the grand prize round in 10 recent episodes of the US *Wheel of Fortune*.

It's a small sample size, but my preliminary findings broadly reflected what Richard reported: in seven out of the 10 episodes, the contestant selected the third category option offered.

But why?

Semmler suggests that a process known as differentiation and consolidation might be at work. "We know from lots of research that as people are trying to make a decision, they will discount particular attributes of an option to make themselves feel more confident after they've made a decision," she says.

Under pressure, the contestants could be discounting the first two options simply because they were seen first, then convincing themselves that the third category has to be the best one. "It's quite a pervasive effect across a lot of different types of decision-making scenarios and situations," says Semmler.

Is the order really the most important factor?

However, there was another correlation in my very small dataset that might be in play. Some of the categories were general, with one-word names – examples include "place" and "thing" – while others were more complex, like "living things", "food and drink", or "what are you wearing?"

These "complex" categories weren't offered in every episode I watched, but in seven out of the eight episodes where they were offered, the contestant picked them.

"If the third category is distinctive somehow, then it might be more salient than the other two," says Adrian Camilleri, a senior lecturer at the University of Technology Sydney with a background in consumer psychology and organisational behaviour. He doesn't watch *Wheel of Fortune*.

Camilleri suggests this could be related to the "decoy effect"– a consumer behaviour phenomenon where an unattractive "decoy" option nudges you to pick a particular product over a competitor.

BGBLUE / GETTY IMAGES

What’s more, a more complex category might seem to give you a better shot at finding the correct answer, because it’s more specific. “What are you wearing?” feels like it narrows the field of possible answers a lot more than “thing” does.

The single instance I saw of a contestant rejecting a “complex” category – namely, “in the kitchen” – had a specific reason attached. “I try to stay out of the kitchen, so I’m gonna go ‘phrase’,” the contestant quips.

But what about the two episodes without a complex category? In both, the contestant selected “phrase” over “event” and “thing(s)” – lending further credence to the theory that contestants tend to choose the most specific, or distinctive, category available.

If we accept “phrase” as the most specific category for these two episodes, contestants selected the most specific option nine of out 10 times.

Putting the scientific process to work

It’s an intriguing thought, but with a sample size of 10 and no psychological expertise, my research isn’t very reliable. I asked Semmler how she would go about empirically testing whether the order truly influences which category people choose.

“You could obviously shuffle the alternatives and see whether or not it’s actually not so much what’s being offered but where it’s being offered in the sequence,” she says.

Another approach could be to ask contestants to rate their confidence in all three options to test whether they *do* tend to select the category they have the greatest confidence in.

Finally, researchers could apply a decision-making model based on specific rules and evaluate how well its predictions capture people’s actual behaviour.

“That could help you to understand what the underlying process is that people are using to choose,” Semmler says.

And of course, it would be helpful to know what *Wheel of Fortune*’s producers are thinking about when they pick the categories and the order they’re presented in – are they trying to nudge us, after all? I’m not sure we’ll be able to find that out anytime soon.

Matilda Handsley-Davis

RATSANI / GETTY IMAGES

Why do blades on fans, aeroplane propellers and car radiator fans look like they are spinning backwards at a certain speed?

– Vincenzo

This has probably happened to you: you’re watching a video of a car driving or an aeroplane flying with a propeller. As the wheels or propeller speed up, at some point they appear to stop moving, or even rotate in the opposite direction.

Or maybe you’ve switched on a fan and seen the blades appear to spin backwards as you watched. What’s going on?

A phenomenon known as the “wagon-wheel effect” is most likely at work.

You may already know that videos, TV shows and films don’t show truly moving images. Instead, they display a series of still images – frames – in quick succession. It’s like a flip-book animation – if you turn the pages slowly, you see a series of drawings changing slightly from one page to the next. If you flip through the pages rapidly, the drawings appear to move.

Now, think about a circular object with straight lines running from the centre of the circle to its perimeter – like the spokes on a wheel, the blades on a fan or propeller, or even the arms on an analogue clock.

As the object rotates, the lines move around the circle. If you take a series of pictures of the object, the position of the lines will change slightly in each one.

If the object completes a single rotation (or two, or 100) in between one frame and the next, the lines will be in exactly the same position in both frames – it will look like they haven’t moved at all. If the object completes slightly less than a full rotation between frames, the lines will look like they’re slightly behind where they were in the previous frame. This gives the illusion of spinning backwards.

If the object spins faster and faster, the lines become blurred enough that the effect disappears, as we can no longer differentiate the individual lines.

The same effect can be created in real life under a strobing or flickering light, such as a fluorescent light. The flickering light has a similar effect of separating what you see into separate “frames” rather than continuous movement.

There are other mechanisms that can produce a similar effect. Remarkably, a 1967 paper in the journal *Nature* reported that humming at specific frequencies could cause the eyes to vibrate and recreate the wagon-wheel effect under constant lighting. Others have reported that the vibrations of a moving car’s engine, or even eating crunchy foods while watching TV, can create a wagon-wheel illusion (we encourage readers to test out that last one at home).

Neuroscientists don’t yet agree why the wagon-wheel effect may occasionally occur under constant lighting. The leading theory is that it’s due to our brains creating multiple interpretations of ambiguous images. Another idea – less accepted – is that our vision actually works similarly to a video camera, processing distinct frames rather than continuous movement.

Matilda Handsley-Davis

WHERE IN THE COSMOS?

Send us a pic of where you're reading *Cosmos* to win a copy of *Best Australian Science Writing!*

SOAKIN' UP THE SCIENCE

Kudos to Cosmos fan Anna Cameron for using a copy of what appears to be Issue 92 (Swamp Sentinels, pg76) as protection from the blazing rays at Minjerribah – or North Stradbroke Island. "Always a fascinating read," writes Anna. To which we reply: "Always a pleasure." We'd love to see where you're reading! Please send us a shot of your special science place: **contribute@cosmosmagazine.com**.

GUESS WHO?

QUESTION

Whose Law? Decode where s = ●

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HINT:

Born in the 18th century, he was a French scientist and balloonist.

MIND GAMES

Who Said?

NO.21

"The obsession with putting ourselves at the centre of everything is the bane not only of theologians but also of zoologists." (4,6)

	1	2	3	4	5	6	7	8	9	10
I		■	■		■			■		
II					■					
III										
IV										
V										
VI										
VII							■			
VIII		■					■		■	

INSTRUCTIONS

Answers to each of the clues in columns 1 to 10.
Row VI reveals the answer.

CLUES AND COLUMNS

1 With a hardness of 7, which blue to purple quartz did the ancient Greeks believe helped prevent intoxication? (8)

2 Which constellation, named by de Lacaille in 1756, sits between Cetus and Phoenix? (6)

3 In linguistics, what is a place name derived from a topographical feature? (7)

4 What adjective is applied to the process of mountain making? (8)

5 Especially in the Australian Alps, what is a free roaming feral horse? (6)

6 What is the largest lake in South America and the world's highest large lake? (8)

7 Until the early nineteenth century, a shower of what was considered to be an atmospheric, not astronomical, phenomenon, such as lightning? (6)

8 In anatomy, what is the fold of the peritoneum that passes between either the stomach and the transverse colon or the stomach and the liver? (7)

9 Researched by the inventor and physicist von Tschirnhaus in 1708, in which German town were deposits of hard-paste porcelain discovered and a pottery established in 1710? (7)

10 In the plural, what are the free-swimming larvae of the coelenterate? (8)

Cosmos Codeword

NO.21

11	10	19	18	7	15	■	18	9	22	12	12	4	15	14
7	■	4	■	20	■	7	■	10	■	22	■	1	■	15
5	7	2	6 K	17	■	20	13	9	17	1	25	17	11 N	7
4	■	25	■	24	■	2	■	9	■	■	■	24	■	4
26	15	22	2 C	6	9	7	■	7	8	10	4	26	17	15
22	■	11	■	7	■	24	■	14	■	11	■	15	■	13
23	22	7	16	9	7	24	24	■	3	15	7	17	11	■
7	■	15	■	7	■	■	■	21	■	7	■	1	■	22
■	14	13	24	26	17	1	22	4	■	4	1	25	22	14
26	■	■	■	17	■	4	■	2	■	9	■	7	■	22
16	7	18	22	11	4	15	■	6	11	22	26	■	5	17
7	■	4	■	■	■	4	■	1	■	24	■	6	■	9
9	4	15	23	4	■	5	25	17	24	26	9	22	6	7
23	■	5	■	24	■	17	■	26	■	22	■	16	■	2
7	9	7	1	25	4	11	26	■	24	2	15	22	1	26

1	2	3	4	5	6	7	8	9	10	11	12	13
14	15	16	17	18	19	20	21	22	23	24	25	26

Codeword requires inspired guesswork. It is a crossword without clues. Each letter of the alphabet is used and each letter has its own number. For example, 'A' might be 6 and 'G' might be 23.

Through your knowledge of the English language you will be able to break the code. We have given you three letters to get you started.

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It Figures

NO.21

	1	2	3	4
A				
B				
C				
D				

INSTRUCTIONS

Using the clues below place the numbers 1 to 16 correctly in the grid. How many clues do you need?

LEVEL 1 – CHIEF SCIENTIST

1 Every composite number less than 15 is adjacent to exactly two of its factors.
2 The only non-prime number in Row A is the highest in that row.
3 The numbers in Row D are all divisible by 3.
4 The product of the down sloping diagonal is 30.
5 The sum of the last two numbers in Column 1 is 26.

LEVEL 2 – SENIOR ANALYST

6 The numbers in Row B are all even.
7 The number beginning Column 1 is half as big as the number directly below it.

LEVEL 3 – LAB ASSISTANT

8 There are two square numbers in Column 4.

SOLUTIONS: COSMOS 94

CODEWORD

A	B	S	O	L	U	T	E	■	W	H	E	E	Z	E
N	■	A	■	■	■	I	■	P	■	O	■	X	■	L
A	F	F	L	U	E	N	C	E	■	A	M	P	L	E
L	■	E	■	S	■	C	■	E	■	R	■	L	■	V
Y	O	G	H	U	R	T	■	R	A	D	I	A	T	E
T	■	U	■	A	■	U	■	L	■	S	■	I	■	N
I	■	A	L	L	E	R	G	E	N	■	G	N	A	T
C	■	R	■	■	■	E	■	S	■	P	■	■	■	H
■	I	D	I	O	M	■	A	S	P	I	R	I	N	■
S	■	■	■	C	■	A	■	■	■	Q	■	O	■	F
K	E	R	A	T	I	N	■	J	O	U	R	N	A	L
E	■	■	■	A	■	S	■	A	■	A	■	I	■	Y
W	R	O	N	G	■	W	I	D	E	N	■	C	H	I
E	■	F	■	O	■	E	■	E	■	C	■	■	■	N
R	E	F	I	N	E	R	Y	■	C	Y	B	O	R	G

1 K	2 F	3 J	4 A	5 S	6 M	7 I	8 X	9 Q	10 W	11 O	12 H	13 T
14 G	15 L	16 B	17 U	18 N	19 E	20 P	21 Y	22 Z	23 V	24 R	25 D	26 C

IT FIGURES

15	2	1	3
7	8	4	10
11	5	6	14
16	12	9	13

WHO SAID?

Sally Ride
The first known LGBTQ astronaut, Ride was a phycisist who went on to become the first American woman in space. She passed away from pancreatic cancer in 2012 at the age of 61.

WHOSE LAW? ANSWER:

The weight of any element liberated during electrolysis is proportional to the quantity of electricity passing through the cell and also to the equivalent weight of the element.
Faraday's Law

David Hamilton

MAMMOLOGIST

One senses that, from his earliest years growing up in Scotland, David Hamilton was a hard child to keep track of. He's clear that a fascination with animals took hold when he was very young.

"My mother's got pictures of us on holiday in various spots and invariably I'm off somewhere in the corner of the photo, looking for frogs or a squirrel somewhere," he says.

Hamilton kicked off adulthood with a bachelor's degree in zoology at the University of Aberdeen and a master's in wildlife biology and conservation at Edinburgh Napier University. His first proper mammal fieldwork was on the Kalahari Meerkat Project in northern South Africa: "It's a fantastic site, and they've got a whole bunch of habituated meerkats and yeah, you can make really in-depth observations on these animals."

In 2014 he turned from placental mammals to marsupials: he moved to Australia and started a PhD investigating Tasmanian devils and devil facial tumour disease in northern Tasmania.

His PhD was conferred in 2020, devils led to quolls and now here we are: Dr Hamilton is these days a conservation ecologist with the Tasmanian Land Conservancy and his special subject is eastern quolls – which he's backing in for the win in the first *Cosmos* Australian Mammal of the Year poll.

"Being European and coming across here and starting to work with marsupials… you've heard a lot of the big classes of marsupials – the koalas and the wombats through to the kangaroos – but I had never heard much about quolls," he says. "I'll never get over my first look at a quoll and how gobsmacked I was by what a unique and wonderful little animal they are. They just took my breath away."

> "My mother's got pictures on holiday and invariably I'm off in the corner of the photo, looking for frogs or a squirrel"

READ ABOUT OUR AUSTRALIAN MAMMAL OF THE YEAR POLL ON PAGE 25.

COURTESY OF DAVID HAMILTON

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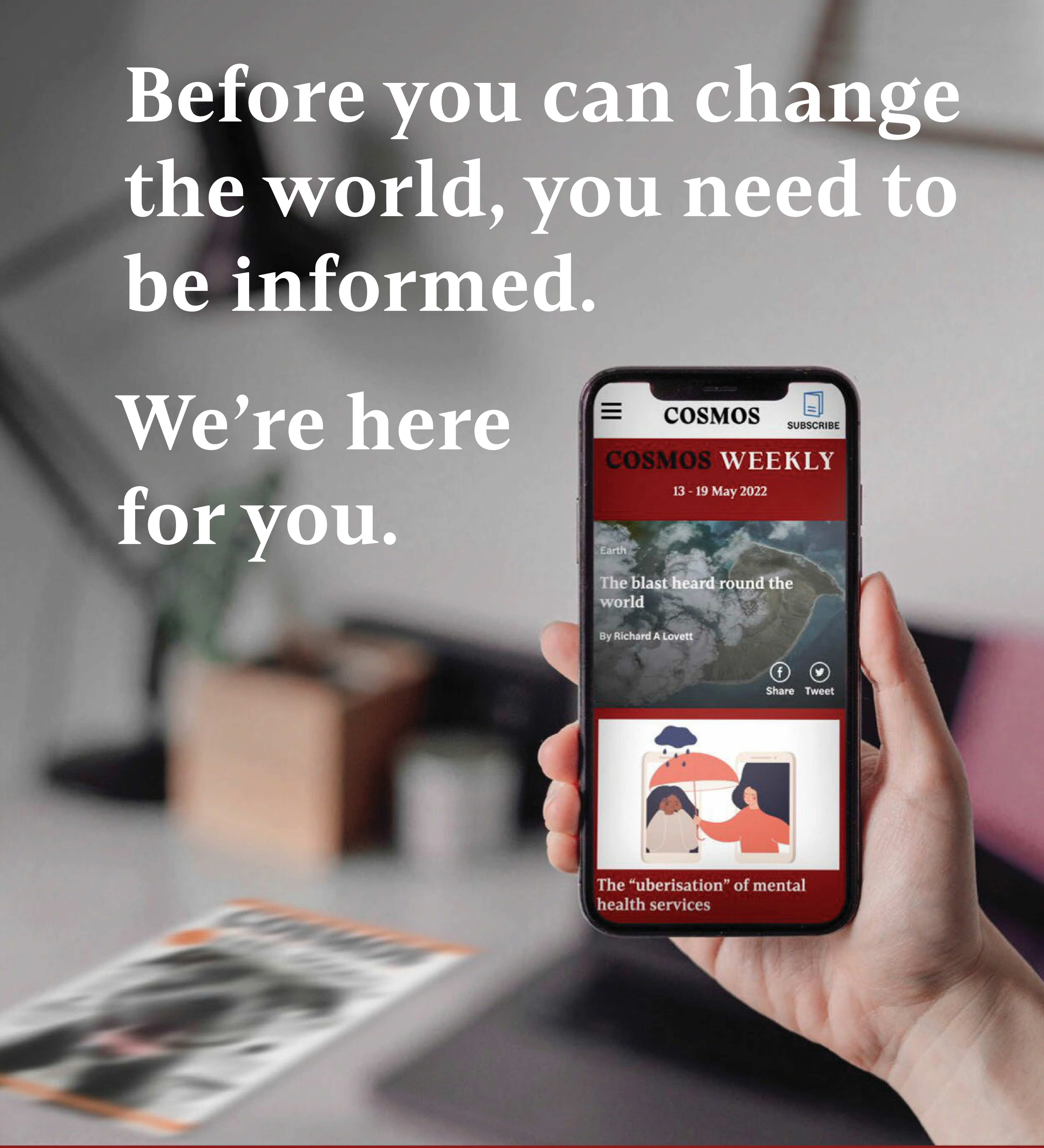

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